Annotated Bibliography of Large Organic Debris (LOD) with Regards to Stream Channels and Fish Habitat

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ANNOTATED BIBLIOGRAPHY OF LARGE ORGANIC DEBRIS (LOD) WITH REGARDS TO STREAM CHANNELS AND FISH HABITAT.

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ABSTRACT

Thomson, B. 1991. Annotated Bibliography of Large Organic Debris (LOD) with Regards to Stream Channels and Fish Habitat. MOE Technical Report No. 32. 93p.

This bibliography is an annotation of the scientific literature published on large organic debris (LOD) or coarse woody debris (CWD) with regards to stream channels and fish habitat. The references primarily document studies conducted within the boundaries of northwestern United States, southeastern Alaska and British Columbia, Canada. A few other selective references from outside this geographic area are also included. The bibliography includes those articles published between 1973 to 1990, although a few selected references published prior to 1973 have also been included. This bibliography includes a total of 129 references of which 107 are annotated.

Large organic debris is an integral component in the ecology of the stream system. Large organic debris plays a major role in modifying both the biological and physical characteristics of small and intermediate sized streams and to a lesser extent those of large sized streams. The debris increases the diversity of aquatic habitat and the hydraulic complexity of the stream channel. Large organic debris provides nutrients and substrate for biological activity as well as providing protective cover and backwater areas along the stream margin for juvenile and adult fish. Locally, stable LOD influences channel morphology by the formation of steps in the channel longitudinal profile which help to dissipate energy of flowing water and can act as a traps and/or dams for the storage of organic and inorganic sediment. Stable debris can increase pool frequency and stream depth variability, maintain and anchor the position of pools along the direction of the stream, and influence lateral migration of the stream channel and formation of secondary channel systems. Removal of stable LOD reduces the channel stability and the quality of pools and cover. Downstream spawning and rearing habitats may be damaged by large increases in sediment released from storage when stable debris is removed. In smaller and mid sized streams the proportion of riffles tends to increase and pools decrease with the removal of stable debris.

ACKNOWLEDGEMENTS

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INTRODUCTION

The primary purpose of this bibliography was to compile the majority of the publications into a ready reference source for researchers, resource managers and other interested parties. It is hoped that the bibliography will serve as a useful starting place for those interested in large organic debris (LOD) or coarse woody debris (CWD) and its effect on stream channels and fish habitat. LOD or large organic debris is defined as woody material greater than 10 cm in diameter (Froehlich, 1975).

The Bibliography primarily documents studies conducted within the boundaries of British Columbia Canada, and southeast Alaska, Washington, Oregon, and northwestern California of the United States. Several other references from outside this geographic area have also been included in this Bibliography as they have been referenced on numerous occasions through out the literature.

The dates of publication of the references spans the period from 1973 to the present (1990). For publications prior to 1973 the reader is referred to the publication by Gibbons and Salo (1973). A few selected articles published prior to 1973 are also included in the bibliography as they are quoted on numerous occasions throughout the literature.

Whenever possible, the abstract or the authors summary or conclusions were used for the annotation. Where these were not available, a brief summary of the article by the present author was used. Several references in the Annotated Bibliography were unavailable to the present author at the time of press. These references are included in the annotated listings but are without annotation. A list of these references can be found under Appendix V at the end of the Bibliography.

References are listed alphabetically by authors name and are consecutively numbered (article reference number). Cross reference of the article and annotation is accomplished by referring to the article reference number, authors name and/or year of publication.

Appendices listing references indexed by; subject, alphabetically by author, chronologically by publication date, by geographic area where the study was undertaken, and an index listing alphabetically by author those references not annotated are included at the end of the Annotated Bibliography.

ANNOTATED BIBLIOGRAPHY

1. **Andrews, E.D.** 1982. Bank Stability and Channel Width Adjustment East Fork River, Wyoming. Water Resources Res. 18(4): 1184-1192.

Frequent surveys of eight cross sections located in self-formed reaches of the East Fork River, Wyoming, during the 1974 snowmelt flood showed a close relation between channel morphology and scour and fill. Those cross sections narrower than the mean reach width filled at discharges less than bankfull and scoured at discharges greater than bankfull. The accumulation and depletion of sand-sized bed material in a cross section was concentrated in the near bank parts of the stream channel and thus significantly influenced bank stability and retreat. In those cross sections that scour at discharges greater than bankfull, the basal bank material is eroded and the banks become undercut and unstable. Conversely, in those cross sections that fill at discharges greater than bankfull, the basal bank material is covered by the accumulated sand-size material and is not eroded. Streambanks in these cross sections are moderately inclined and stable. A resurvey in the summer of 1980 of the cross sections located in straight reaches showed that those cross sections which scoured at discharges greater than bankfull had become 2-4 feet wider, whereas those cross sections which filled at discharges greater than bankfull were unchanged. Thus bank stability and to some extent the adjustment of stream channel width in the East Fork River study reach appears to be controlled by the processes of scour and fill.

2. **Andrus, C.W., B.A. Long, and H.A. Froehlich.** 1988. Woody Debris and Its Contribution to Pool Formation in a Coastal Stream 50 Years after Logging. Can. J. Fish. Aquat. Sci. 45(12): 2080-2086.

Large quantities of woody debris persisted 50 yr after logging and fire in stream channels of a small coastal Oregon watershed. Debris from the current stand represented only 14% of total debris volume and 8% of debris volume responsible for creating pools. The greatest number of pools were located in downstream sections of the watershed where gradient was reduced, discharge was increased, and streambed material was finer. Seventy percent of pools with a volume greater than 1.0 m^3 were associated with woody debris in the channel. Composition of the current riparian forest varied with topography. Alder stands dominated moist terrace sites adjacent to channels, whereas slopes contained a mixture of alder and conifer. Study results indicate that riparian trees must be left to grow longer than 50 yr to ensure that an adequate, long-term supply of woody debris is available to stream channels. Debris from previous stands plays a crucial role in the interim and should not be removed from stream channels.

3. **Angermeier, P.L. and J.R. Karr.** 1984. Relationships Between Woody Debris and Fish Habitat in a Small Warmwater Stream. Trans. Am. Fish. Soc. 113: 716-726.

Abundance of woody debris was manipulated in a small Illinois stream to determine the importance of this material to fish. When a stream reach was divided along mid channel, and debris was added to one side, but removed from the other, fish and benthic invertebrates were usually more abundant on the side with woody debris than on the cleared side. In further experiments during a low-flow year (1980), debris removal was followed by rapid decreases in water depth and occurrence of benthic organic litter, and increases in current velocity and proportion of sand bottom. These changes were less apparent in unaltered reaches during 1980, and in all reaches during 1981, which was a high-flow year. Artificial debris was colonized by many invertebrates, including chironomids, trichopterans, and ephemeropterans. Most large fish (age 2+) avoided reaches without debris, whereas some smaller fish (such as johnny darter) preferred them; preferences for reach treatments were stronger in 1980 than in 1981. the adaptive significance of associations between fish and woody debris appeared more closely related to the advantages of camouflage than those of increased food availability or protection from strong currents. Extensive removal of woody debris may disrupt structure and function in small streams, especially low-gradient ones. If the biological integrity of stream resources is to be maintained despite agricultural and urban uses, less disruptive management protocols will need to be employed.

4. **Baker, C.O.** 1979. The Impacts of Logjam Removal on Fish Populations and Stream Habitat in Western Oregon. M.Sc. Thesis, Oregon State University, Corvallis, Oregon, 81p.

A study of logjam removal operations in western Oregon was conducted from 1976-1978. Seven removal sites were monitored, three in Cascade streams, and four on coastal watersheds. The principal objectives of the study were to compare various methods of logjam removal and quantify the short-term impacts of removal on downstream fish populations and fish habitat.

Electroshocking was utilized to monitor population changes above and below the logjam removal sites. Periodic mapping of downstream pools and reprofiling of jam removal sites were utilized to monitor post-removal habitat changes.

The principal short-term impact of logjam removal was the release of trapped sediment and debris behind the jam and the destruction of existing habitat within the logjam. Erosion at the seven removal sites ranged from 135 m^3 to 1079 m^3. The major portion of the eroded sediment consisted of size fractions less than 3.3 mm in diameter.

Fish populations below logjam removal sites remained at levels generally equal to or exceeding pre-removal quantities. This persistence was attributed to sediment deposition patterns that did not significantly affect certain fish habitats, as well as an ability of fish to tolerate some sediment deposition. The presence of the 1976-1977 winter drought had a pronounced influence on population changes, post-removal habitat changes, and overall interpretation of data.

5. **Bennett, J.R. and M.J. Selby.** 1977. Induced Channel Instability and Hydraulic Geometry of the Mangawhara Stream. New Zealand J. Hydrol. 16(2): 134-147.

Approximately 50 percent of the Mangawhara catchment has been converted from forest to pasture in the last 50 years. Streamflow is now more responsive to intense rainfalls and the supply of bedload to the channel has increased as a result of landsliding on the slopes. It has been suggested by Schumm (1971) that increases in bedload and water discharge will be accompanied by increases in channel width, meander wavelength, and width-depth ratio and by a decrease in sinuosity. Changes in gradient and depth may be in either direction. For the Mangawhara all recorded changes are as suggested, while both gradient and depth changes are small and of uncertain direction. Measures of the hydraulic geometry both at-a-station and downstream obey the laws established for rivers elsewhere.

6. **Berry, J.D.** 1975. Modelling the Impact of Logging Debris in Streams. In Proceedings: Watershed Management Symposium. Logan, Utah, Aug. 11-13, 1975, American Society of Civil Engineers, New York.

7. **Beschta, R.L.** 1979. Debris Removal and Its Effects on Sedimentation in an Oregon Coast Range Stream. Northwest Science 53: 71-77.

The removal of large organic debris obstructing anadromous fish passage in a Coast Range stream in Oregon accelerated downcutting of previously stored sediments. As a result, turbidity and suspended sediment levels increased during several storms after debris removal. Streamflow eroded more than 5,000 m^3 of sediment along a 250 m reach the first winter after debris removal. Therefore, fisheries managers who want to remove debris jams from streams must consider the stored sediments that will be scoured from the stream beds and deposited downstream.

8. ___________ 1983a. The Effects of Large Organic Debris Upon Channel Morphology: A Flume Study. In Li, R. and P.F. Lagasse (eds.): Proceedings: D.B. Simons Symposium on Erosion and Sedimentation, Simons, Li, and Assoc., Fort Collins, Colorado, 8-63 to 8-78.

9. ___________ 1983b. Sediment and Organic Matter Transport in Mountain Streams of the Pacific Northwest. In Li, R. and P.F. Lagasse (eds.): Proceedings: D.B. Simons Symposium on Erosion and Sedimentation, Simons, Li and Assoc., Fort Collins, Colorado, 1-69 to 1-89.

10. ___________ **and W.S. Platts.** 1986. Morphological Features of Small Streams: Significance and Function. Water Resources Bull. 22(3): 369-379.

Throughout the United States, land managers are becoming increasingly aware of the importance of small streams for a wide range of resource benefits. Where channel morphology is modified or structural features are added, stream dynamics and energy dissipation need to be considered. Unit stream power, defined here as the time-rate loss of potential energy per unit mass of water, can be reduced by adding stream obstructions, increasing channel sinuosity, or increasing flow resistance with large roughness elements such as woody root systems, logs, boulders,or bedrock. Notable morphological features of small streams are pools, riffles, bed materials, and channel banks. Pools, which vary in size, shape, and causative factors, are important rearing habitat for fish. Riffles represent storage locations for bed material and are generally utilized for spawning. The particle size and distributions of bed material influence channel characteristics, bedload transport, food supplies for fish, spawning conditions, cover and rearing habitat. Riparian vegetation helps stabilize channel banks and contributes in various ways to fish productivity. Understanding each stream feature individually and in relation to all others is essential for proper stream management. Although engineered structures for modifying habitat may alter stream characteristics, channel morphology must ultimately be matched to the hydraulic, geologic, and (especially) vegetative constraints of a particular location.

11. **Bilby, R.E.** 1977. Factors Relating to the Distribution of Organic Debris Dams in the Stream Ecosystems. Abstract 40th Annual Meeting Amer. Soc. Liminology and Oceanography.

12. _________ 1979. The Function and Distribution of Organic Debris Dams in Forest Stream Ecosystems. Ph.D. Thesis. Division of Biological Sciences, Cornell University.

13. __________ 1981. Role of Organic Debris Dams in Regulating the Export of Dissolved and Particulate Matter from a Forested Watershed. Ecology 62(5): 1234-1243.

An organic debris dam is an accumulation of organic matter in a stream which obstructs water flow. Debris dams trap sediments in the pool formed upstream from them and the dam structure itself collects particulate matter.

This study was done at Hubbard Brook Experimental Forest, in New Hampshire, to examine the relative importance of these structures in retention of sediment and organic matter in a small stream ecosystem. An experimental approach was used in which all organic debris dams were removed from a 175-m section of second-order stream, just above a gauging weir. The material being exported from the watershed was separated into three size categories: dissolved matter (<0.5 m), fine particulate matter (0.5 m to 1 mm), and coarse particulate matter (>1mm). Export of each size fraction was monitored for at least 1 yr prior to dam removal, and for 1 yr following removal.

Following dam removal, export of dissolved matter increased slightly due to an increase in the concentration of dissolved organic carbon in the stream water during periods of high discharge. Fine particulate matter export increased dramatically at high discharges following dam removal; concentrations in some instances achieved values five times higher than any observed before dam removal. Coarse particulate matter was also greatly increased.

Calculating dissolved matter and particulate matter export from the watershed, with and without organic debris dams, showed that dam removal brought about a 6% increase in the export of dissolved matter and a 500% increase in the export of both fine particulate and coarse particulate matter.

14. __________ 1984. Removal of Woody Debris May Affect Stream Channel Stability. Journal of Forestry 82: 609-613.

Several western states mandate the removal of logging debris from streams in order to prevent accumulations impassable to anadromous fish. Monitoring a small western Washington stream revealed large changes in channel structure during the first high flow after cleaning. Nearly 60 percent of the monitored pieces of debris moved during this storm, channel cross sections were substantially altered by movement of stored sediment, and the number, area, and volume of pools decreased. The degree of channel rearrangement was greater than in a comparable undisturbed stream. Subsequent storms caused much less debris movement and channel change than the first high flow, even though some of the later flows were of greater magnitude. An interim guide to stream cleaning is prescribed.

15. __________ 1985. Influence of Stream Size on the Function and Characteristics of Large Organic Debris. p. 1-14. In Proceedings: West Coast Meeting of the National Council of the Paper Industry for Air and Stream Improvement, Tech. Bull. 466, Portland, Oregon.

Large woody debris in streams influences the physical form of the channel, movement of sediment, retention of organic matter and offers cover for fish.

Present debris management schemes focus on cleaning of channels after timber harvest and generally mandate removal of all material entering a stream during a logging operation. In practice, old debris is often disturbed or removed during the cleaning, and as a result, streams are generally debris-poor following the cleaning. A second aspect of debris management is how to supply new material over time to replace pieces washed downstream or lost through decomposition. The discussion presents some preliminary data on the influence of stream size on debris size, frequency and function.

A study during the winter of 1980 and 1981 indicated that two factors which seem to contribute to debris stability were size and features of the channel which anchored the debris in place. Length of debris related closely to its stability. Pieces less than 2.5 m in length were far more likely to move than longer pieces and debris over 10 m in length rarely moved. Diameter was also related to debris stability. Pieces less than 50 cm in diameter moved much more frequently than pieces larger than 50 cm. Degree of anchoring or burial was also closely related to debris stability. Pieces not buried in the bank or bed were more apt to move than those with anchoring. No pieces of debris having both ends and upstream face buried moved during the study period.

Based on these relationships a set of debris management guidelines were formulated for this stream. However, it is obvious that a piece of debris large enough to be stable in the study stream might not be in a larger system. Therefore, establishment of the relationship between stream size and debris size is essential to the formation of general stream clearing guidelines.

Presently a study examining the relationship between stream size and characteristics of woody debris is being undertaken. The first phase of the study focused on streams flowing through old-growth timber. Information collected for each piece of debris include the length in and out of the channel, diameter, species, proportion of channel spanned and oriented to streamflow. In addition, features adding to the stability of the piece are noted, such as degree of burial, presence of a rootwad or bracing by boulders, bedrock outcrops or other pieces of debris. Channel characteristics associated with debris which are measured include size of sediment accumulations, height of debris formed waterfalls and the surface area of pools influenced by debris. These data will be used to determine how the size of a stream influences the size of debris found in that stream and how debris size relates to the size of channel features influenced by it.

Preliminary data would indicate that there is a clear relationship between debris length and diameter and streamsize. It is fairly evident that as stream size increases, the size at which a piece of debris is stable also increases. The frequency of occurrence of debris decreases as stream size increases. Only the largest pieces of debris were stable in the largest streams while both the large and smaller pieces were able to maintain position in the smaller channels. Thus, more debris was found in smaller channels.

The study streams were separated into three categories based on channel width; less than 7 m, 7-10 m and greater than 10 m. In the smallest streams there is little relationship between debris size and pool area. However, as stream size increases, pool surface area responds to debris size more closely and this relationship is quite evident in streams with channel width over 10 m.

Pool formation by woody debris in streams is generally caused by scour of the bed or the bank due to flow deflection. The data indicate that in small streams debris size does not play a major role in dictating the degree of scour and thus the extent of pool. In larger streams, however, due to the greater discharge, a large piece of debris may be able to deflect a larger proportion of the stream flow thereby increasing the erosive pressure exerted on the bank or bed and yielding a larger pool. Thus, for pool formation, larger streams will benefit from larger pieces of debris. This does not seem to be the case in small systems.

With this information we will be able to determine the kinds of streams in which debris input requirements can be met with present forest management practices and those which will require some alternative scheme to ensure a continued supply of appropriately sized woody debris. Once the type of debris can be matched to with stream size, the amount of wood needed for a given stream has to be determined. There is no reason to assume that old-growth loading levels in amy way approximates the ideal situation, as far as fish are concerned. A great deal more work needs to be done before we understand the role played by woody debris in determining fish production in forest streams.

16. __________ **and G.E. Likens.** 1980. Importance of Debris Dams in the Structure and Function of Stream Ecosystems. Ecology 61: 1107-1113.

Removal of all organic debris dams from a 175-m stretch of second-order stream at the Hubbard Brook Experimental Forest in New Hampshire led to a dramatic increase in the export of organic carbon from this ecosystem. Output of dissolved organic carbon (<0.50 *m-1 mm) export increased 632% and coarse particulate organic matter (.1 mm) export increased 138%.

Measurement of the standing stock of coarse particulate organic matter on streambeds of the Hubbard Brook Valley revealed that organic debris dams were very important in accumulating this matter. The proportion of organic matter held by dams drops to 58% in second-order streams and to 20% in third-order streams.

Organic debris dams, therefore, are extremely important components of the small stream ecosystem. They retain organic matter within the system, thereby allowing it to be processed into finer size fractions in headwater tributaries rather than transported downstream in a coarse particulate form.

17. _________ **and J.W. Ward.** 1989. Changes in Characteristics and Function of Woody Debris with Increasing Size of Streams in Western Washington. Trans. Am. Fish. Soc. 118: 386-387.

In second to fifth order streams that drain old-growth timber in western Washington, characteristics and function of woody debris changed in relation to stream size. Average diameter, length, and volume of pieces of wood increased as streamsize increased, whereas the frequency of occurrence of woody debris decreased. In streams with channel widths less than 7 m, 40% of the pieces of debris were oriented downstream. The types of pools most commonly associated with pieces of wood changed from plunge pools in small streams (42%) to debris scour pools in larger systems (62%). Pool area was correlated with the volume of the piece of wood forming the pool in streams of all sizes. However, this relationship was most evident in larger channels. Nearly 40% of the pieces of wood in channels less than 7 m wide were associated with sediment accumulations. Less than 30% of the pieces retained sediment in channels from 7 to 10 m wide, and less than 20% retained sediment in channels greater than 10 m wide. Surface area and sediment accumulations and the volume of the pieces of wood forming the accumulations were related in all streams, but the relationship was clearest in the larger channels. Accumulations of particulate organic matter associated with woody debris were more frequent in small streams but were larger in large streams. No relationship was observed between the volume of fine particulate organic matter accumulated by a piece of wood and the piece of wood's volume.

18. **Bisson P.A. et al.** 1987. Large Woody Debris in Forested Streams in the Pacific Northwest: Past, Present and Future. p. 143-190. In Salo, E.O. and T.W. Cundy (eds.): Streamside Management: Forestry and Fishery Interactions. Institute of Forest Resources Contribution No. 57, University of Washington, Seattle, Washington.

This paper reviews the form, function, and management of woody debris in streams, and reaches three major conclusions: (1) Large woody debris enhances the quality of fish habitat in all sizes of stream. (2) Removal of most trees in the riparian zone during logging, combined with thorough stream cleaning and short-rotation timber harvest, has altered the sources, delivery mechanisms, and redistribution of debris in drainage systems, leading to changes in fish population abundance and species composition. (3) There is an urgent need for controlled field experiments and long-term studies that focus on the protection of existing large woody debris in stream channels and the recruitment of new debris from the surrounding forest.

Woody debris has long been considered a potential source of logjams that could block river navigation, water-based log transport, and the upstream passage of salmon and trout on their way to spawning grounds, but is now understood to play an important role in the creation and maintenance of fish habitat throughout entire rivers. Although wood itself eventually enters the food web of the stream ecosystem as it gradually decays, the major importance of debris lies in its structural characteristics and the way these features influence channel hydraulics. Physical processes associated with debris in streams include the formation of pools and other important rearing areas, control of sediment and organic matter storage, and modification of water quality. Biological properties of debris-created structures can include blockages to fish migration, provision of cover from predators and from high streamflow, and maintenance of organic matter processing sites within the benthic community. The locations and principal roles of woody debris change throughout the river system. In steep headwater streams where logs span the channel, debris creates a stepped longitudinal profile that governs the storage and release of sediment and detritus, a function that facilitates the biological processing of organic inputs from the surrounding forest. When the stream channel becomes too wide for spanning by large logs, debris is deposited along the channel margins, where it often forms the most productive fish habitat in main-stem rivers. In all but the smallest streams there is some degree of clumping, although the size and spacing of debris clumps generally increase in a downstream direction. Debris-related fish habitat can be found anywhere in small forested streams. In large rivers it is primarily associated with debris accumulations along the margins and secondary channel systems of the floodplain, although it also occurs behind and under very large pieces (intact boles and root wads) along main-stem gravel bars.

Changes in tree species composition, abundance, and input rates to streams resulting from forest management practices have differed according to location in the watershed, and many physical and biological processes have been altered by these changes in the river system's debris load. Several questions have not been fully explored, particularly with regard to the long-term consequences of streamside management for debris recruitment. Yet the majority of studies of streams in second-growth forests have demonstrated that the input of large potentially stable debris from second-growth stands in which nearly all large merchantable trees had been harvested was significantly reduced relative to debris inputs from old-growth stands. Other studies have shown that loss of large debris has led to a shift in stream habitat composition that favoured underyearling steelhead (Salmo gairdneri) and cutthroat trout (S. clarki) at the expense of the older trout age classes as well as both underyearling and yearling coho salmon (Oncorhynchus kisutch). Loss of debris has also reduced overwinter survival of all species. In order to develop procedures that will protect existing instream debris, as well as provide a continued supply of the proper quantity and quality of large woody debris for the future, it will be necessary to test scientifically a variety of management options over a wide range of stream sizes. Many management procedures have been proposed, including techniques for removing slash from stream channels after logging, determining the configuration of buffer strips, selective harvesting within the streamside management zone, and deliberately adding debris to streams for habitat enhancement. Evaluation of these proposals will require a great deal of time and effort, as well as the cooperation of many resource management organizations. However, long-term research is essential in view of the complexity of debris management issues.

19. ____________ et al. 1982. A System for Naming Habitat Types in Small Streams, With Examples of Habitat Utilization During Low Streamflow. p. 62-73. In Armantrout, N.B. (ed.): Proceedings: Acquisition and Utilization of Aquatic Habitat Inventory Information Symposium. Western Division, Am. Fish. Soc., Portland, Oregon, October 28-30, 1981.

Fish habitat in small streams is classified into a number of types according to location within the channel, pattern of water flow, and nature of flow controlling structures. Riffles are divided into three habitat types: low gradient riffles, rapids, and cascades. Pools are divided into six types: secondary channel pools, backwater pools, trench pools, plunge pools, lateral scour pools, and dammed pools. Glides, the last habitat type, are intermediate in many characteristics between riffles and pools. Habitat conditions in four western Washington streams. Most age 0+ coho salmon (Oncorhynchus kisutch) reared in pools, particularly back-waters, and preferred cover provided by rootwads. A few large coho occupied riffles and sought the cover of overhanging terrestrial vegetation and undercut banks. Age 0+ steelhead trout (Salmo gairdneri) selected riffles with large wood debris; while age 1+ steelhead preferred plunge, trench, and lateral scour pools with wood debris and undercut banks. The largest individuals of both steelhead age classes were found in swiftly flowing riffle habitats. Age 0+ cutthroat trout (S. clarki) preferred low gradient riffles but switched to glides and plunge pools when steelhead and coho were present, thus suggesting that they had been competitively displaced from a preferred habitat. Age 1+ and 2+ cutthroat preferred back-water pools when coho were absent but avoided them when coho were present. Cutthroat of all age classes generally favoured cover provided by wood debris in both pool and riffle habitats.

20. __________ **and J.R. Sedell.** 1984. Salmonid Populations in Streams in Clearcut vs. Old-Growth Forests of Western Washington. p. 121-129 In Meehan, W.R., T.R. Merrell, and T.A. Hanley (eds.): Proceedings: Fish and wildlife relationships in old-growth forests symposium. Am. Inst. Fish. Res. Biol.

21. **Bisson P.A., K. Sullivan, and J.L. Nielsen.** 1988. Channel Hydraulics, Habitat Use, and Body Form of Juvenile Coho Salmon, Steelhead, And Cutthroat Trout in Streams. Trans. Am. Fish. Soc. 117: 262-273.

Habitat use by juvenile coho salmon Oncorhynchus kisutch, steelhead Salmo gairdneri, and the coastal subspecies of cutthroat trout Salmo clarki clarki in small streams in western Washington was influenced by hydraulic characteristics of different types of channel units. Coho salmon preferred pools with average velocities less than 20 cm/s; very few fish were found in riffles with high current velocities. Steelhead occurred in riffles and also utilized deep pools with relatively high velocities along the centre of the channel. Cutthroat trout were intermediate between coho salmon and steelhead in their use of swiftly flowing habitats. Variation in body shape and fin size among the three species generally fit the predicted morphologies that would be favoured in different locations within the channel. Coho salmon possessed a deep, laterally compressed body with large median and paired fins. These features are believed to facilitate rapid turns and quick but transient burst swimming. Steelhead possed a more cylindrical body shape with short median fins and relatively large paired fins, attributes that appear well adapted to holding a position in swift water. The cutthroat trout's lack of morphological adaptation to either fast or slow. water may help to explain why this species is dominated by coho salmon and steelhead in areas of sympatry.

22. **Boehne, P.L. and J.R. Wolfe.** 1986. Use of Explosives to Add Large Organic Debris to Streams. North. Am. Jour. Fish. Man. 6: 599-600.

Large conifers were felled by gel dynamite to increase the number of large organic debris pieces in an Oregon Cascade Mountain stream. Dynamited root masses generally consisted of one to six large roots extending about 25-75 cm from the tree base. This technique appears to be useful for stream enhancement where heavy equipment access is not possible and large conifer "blowdowns" are desired.

23. **Bryant, M.D.** 1980. Evolution of Large Organic Debris After Timber Harvest: Maybeso Creek, 1949-1978. USDA Forest Service, Gen. Tech. Rep. No.PNW-101. Pacific Northwest Research Station, Portland, Oregon. 30p.

This paper discusses the role of large debris (tree boles and root wads) in the morphological changes in Maybeso Creek, Prince of Wales Island, Alaska. The objectives were to:
1. Document the general changes in the morphometry of the stream channel as a result of the accumulations of natural and logging debris.
2. Examine the fate of natural accumulations of large debris during and after timber harvest.
3. Discuss the influence of accumulations of natural and logging debris on stability of streams.

Timber harvest caused extensive changes in the stream channel of Maybeso Creek. Some of these changes may have been imposed by equipment operating in the stream, but mostly were related to accumulations of large debris . Natural accumulations appeared stable compared with those created by logging debris. Throughout logging, natural accumulations collected large amounts of logging debris and subsequently washed out.

The absence of old-growth forests along the stream bank effectively eliminated new accumulations. The decrease in the number of accumulations of large debris after logging was apparent. As these accumulations are dissipated, pools formed around accumulations of large debris will be replaced by riffles; thus, there will be a net increase in riffle areas. As these areas stabilize, the stream channel morphology will be determined by rock formations and streambank.

It was evident that large quantities of tree-size material had been assimilated between 1960 and 1978, either within the stream or along the banks. Although amount of debris throughout the active channel has decreased, debris along the bank and projecting into the channel still plays a role in channel morphometry. In some cases, it will contribute to bank stability. These areas will also contribute to the formation of pool areas important to juvenile salmonids.

The observations of these events following logging on Maybeso Creek show that accumulations of large natural debris play an active role in channel morphometry and form relatively stable features, such as pools and side channels. Natural debris accumulations are most severely affected by large floatable logging debris, whereas bedrock areas are generally unaffected.

24. ___________ 1982. Organic Debris in Salmonid Habitat in Southeast Alaska: Measurements and Effects. p. 259-265. In Armantrout, N.B. (ed.): Proceedings: Symposium on Acquisition and Utilization of Aquatic Habitat Inventory Information. Western Division, Am. Fish. Soc., Portland, Oregon, October 23-28, 1981.

Woody debris is an important part of the stream habitat used by juvenile salmonids. As part of an examination of the effects of logging debris and its removal, this study examined some methods for measuring the amount and effects. Several indices of channel morphology were developed from stream cross-section measurements. Some differences were detected. Differences in debris loading following removal were observed, but the patch distribution of debris and changes in stream channel boundaries masked some differences. Stream maps revealed year-to-year bank changes and changes in debris orientation following debris removal. Coho populations appeared to respond to debris removal with fewer numbers in cleared stream sections.

25. ___________ 1983. The Role and Management of Woody Debris in West Coast Salmonid Nursery Streams. North Am. J. Fish. Man. 3: 322-330.

Debris removal is a frequently used management technique for small streams in logged watersheds, but many stream-cleaning techniques overlook important habitat requirements of juvenile salmonids. Reviews of some past management practices show little systematic evaluation or monitoring of physical or biological effects. A review of several studies (most of them not associated with debris removal) shows the importance of woody debris as salmonid habitat. The role of organic debris in small stream system is discussed and a set of criteria for debris removal is proposed.

26. __________ 1985. Changes 30 Years After Logging in Large Woody Debris, and its Use by Salmonids. p. 329-334. In Johnson, R.R., et al., (eds.): Riparian ecosystems and their management: Reconciling conflicting uses. First North American Riparian Conference, Tuscon, Arizona, USDA Forest Service Gen. Tech. Rep. RM-120, Rocky Mountain Forest and Range Experimental Station, Fort Collins, Colorado.

Changes in large woody debris in fourth and fifth-order salmon streams with logged, unlogged, and partially logged riparian zones are documented from maps for 1949 to 1960 and from field surveys done in 1983 and 1984. Over the 30-year period, most changes in the amount of large woody debris occurred in the logged systems. During and immediately after logging large increases were noted, but in 1984 the amount of large woody debris in the logged systems was less than that observed before logging in most categories. Amounts of large woody debris in the other streams remained relatively stable. Thirty years after logging, habitat formed as a result of large debris provides important rearing areas for juvenile salmonids. Results from this study emphasize the importance of managing riparian zones as a source of large organic debris.

27. **Bustard D.R.** 1984. Queen Charlotte Islands Stream Rehabilitation Studies A Review of Potential Techniques. Land Management Rep. No. 28: 31p. Ministry of Forests, Province of British Columbia, Victoria, B.C.

The potential techniques for the rehabilitation of small streams which have been degraded by mass wasting on the Queen Charlotte Islands are reviewed. Experience with possible rehabilitation techniques in other parts of the Pacific Northwest is summarized and suggestions on their applicability for Queen Charlotte Island streams are made. It is stressed that stream rehabilitation is not an alternative to sound habitat protection. Stream rehabilitation should be considered only after an assessment of the factors actually limiting fish production is made. This report summarizes studies and literature results to the end of 1981.

28. **Bustard D.R. and D.W. Narver.** 1975. Aspects of the Winter Ecology of Juvenile Coho Salmon (Oncorhynchus kisutch) and Steelhead Trout (Salmo gairdneri). J. Fish. Res. Board Can. 32(5): 667-680.

The major physical characteristics of overwintering areas for juvenile coho salmon (Oncorhynchus kisutch) and steelhead trout (Salmo gairdneri) are described for a small, unlogged, west coast Vancouver Island stream. During the winter months age I+ coho and steelhead were found at a range of depths mainly greater than 45 cm and in deeper water than age 0 of either species. About 45% of age 0 steelhead observed were in water <15 cm deep. The depth occupied by coho and age I+ steelhead was negatively correlated with water temperature below 8.5 C. Coho were associated less closely with the bottom than were steelhead. At 7 C or less most fish were associated with water velocities of <15 cm/s. Velocities in which steelhead occurred were positively correlated with rising temperature above 4 C. As water temperature decreased from 9 to 2 C, coho and steelhead moved closer to cover. Cover used by coho and age I+ steelhead most frequently was logs and upturned tree roots, although debris accumulations and overhanging banks were also used. Both age groups of coho used overhanging brush but steelhead did not. Over 50% of age 0 steelhead were associated with rocks 10-25 cm in diameter. Sidepools and quiet back channels that contained water only in the winter and that had combinations of the above cover types were populated by coho during the winter. A series of unused beaver ponds, dry in the summer, was an important overwintering area for coho with a survival rate about twice as high as the 35% estimated for the entire stream system.

29. **Canada Department of Fisheries and Oceans and British Columbia Ministry of Environment.** 1980. Stream Channel Improvements. p. 47-59. In Stream Enhancement Guide. Salmon Enhancement Program, Vancouver, British Columbia.

Physical conditions within stream channels can be modified to improve or increase particular habitat for salmonids. However, if such modifications of the channel are to have any degree of permanence and success, they must incorporate the principals of stream hydraulics. The end result will also depend on correct identification of the factors limiting freshwater production of the species in question. For example, there would be no benefit from increasing spawning area for a coho salmon or steelhead trout population if the stream's juvenile rearing capacity were the factor actually restricting production.

In British Columbia, the most common activities for stream channel improvement have been log jam and debris removal, restoration of obstructed side channels, and measures to stabilize unstable reaches of streams affected by floods. However, several channel improvement concepts developed for eastern North American conditions are being evaluated and adapted to suit the more rugged environment of coastal British Columbia.

Some general guidelines to be considered before modifying existing stream features to improve spawning and rearing habitats are included.

30. **Carlson J.Y., C.W. Andrus, and H.A. Froehlich.** 1990. Woody Debris, Channel Features, and Microinvertebrates of Streams with Logged and Undisturbed Riparian Timber in Northeastern Oregon, U.S.A. Can. J. Aquat. Sci. 47: 1103-1111.

Microinvertebrate communities and several aspects of fish habitat were examined for 16 northeastern Oregon stream segments, 11 with undisturbed riparian forests and five where 26-54% of the riparian forest had been harvested 6 to 17 yr previously. Amounts of woody debris in streams and pools formed by the debris were similar between undisturbed and logged sites. Pool volume was inversely related to stream gradient and directly related to the amount of woody debris in the stream. Stream surface substrate composition was not significantly different between streams in logged and undisturbed areas. Micro invertebrate density was 20 to 113 percent greater at the logged sites and diversity was similar at logged and undisturbed sites. Macroinvertebrates were most abundant at lower elevation streams and at streams that were shaded less by the surrounding vegetation. Timber harvesting activities do not appear to have damaged aquatic insect habitat and pool abundance was not altered, suggesting the habitat's carrying capacity for fish was not affected.

31. **Dolloff A.C.** 1986. Effects of Stream Clearing on Juvenile Coho Salmon and Dolly Varden in Southeast Alaska. Trans. Am. Fish. Soc. 115: 743-755.

This paper describes the effects of selective removal of woody debris on populations of juvenile coho salmon Oncorhynchus kisutch and Dolly Varden Salvelinus malma in two small streams of Prince of Wales Island, Alaska, during the summers of 1979-1981. These streams contained debris left when surrounding forests were clear-cut in the late 1960s. Debris smaller than 60 mm in diameter and larger debris not embedded in the stream channel were manually removed from half of the study reach on each stream in 1979 by state-of-the-art techniques. Immigration and emigration of fish from the study sections and intrastream movements were very limited after an initial period of population adjustment in the spring regardless of treatment. Population densities and production of both species were typically higher in sections where debris accumulations had not been removed. Production of age-0+ and age-1+ coho salmon and age-1+ and age-2+ Dolly Varden during the June-September period ranged from 0.70 to 2.22 g/m^2 in the cleaned sections and from 0.84 to 2.10 g/m^2 in the uncleaned sections. Carrying capacities for both species were lower in cleaned sections despite the use of selective techniques for removing woody debris.

32. **Duff D.A. and R.S. Wydoski.** 1982. Indexed Bibliography on Stream Habitat Improvement (Revised 1982). USDA Forest Service, Intermountain Region, Ogden, Utah, 143p.

This updated revision contains 828 references placed alphabetically by author and numbered consecutively. A concise index of 20 key subjects categorizes the references by number for quick review. Most references have been placed under the major key subject to which they are applicable. Key subjects are: environmental planning, fish (coldwater), fish (warm water), fish ecology and behaviour, fishways, general, guidelines, instream structures, invertebrates, livestock exclosures, obstruction removal, riparian vegetation, screens - fish, sedimentation, spawning facilities, streambank stabilization, streamflow (& control), techniques, water quality, and water temperature.

33. **Elliott S.T.** 1986. Reduction of a Dolly Varden Population and Macrobenthos after Removal of Logging Debris. Trans. Am. Fish. Soc. 115: 392-400.

Logging debris resident for five or more years in small streams of southeastern Alaska is frequently removed to improve salmonid habitat. This practice was evaluated for its effects on juvenile anadromous Dolly Varden Salvelinus malma and macrobenthos populations in a small spring-fed stream during 1973-1981. Debris, consisting of limbs, needles, and fragmented logs, was removed by hand from the entire stream in July 1976. The surface area, number, and size of pools was reduced thereafter, and the water velocity increased. Macrobenthos density and invertebrate drift decreased 60-90% immediately after debris removal but returned to pretreatment levels in 1977. The Dolly Varden population decreased from 900 to less than 100 fish by 1978 and then fluctuated sharply between late 1978 and 1981. After 1978, Dolly Varden averaged 27 mm less in length and their biomass decreased from 12.5 to 3.9 g/m^2. Decrease in fish standing crop occurred in two stages: (1) an initial loss of larger fish due to reduced habitat; (2) loss of smaller individuals during November freshets thereafter. This study indicates that removal of old logging debris does not improve habitat and can result in smaller rearing populations. Old debris should not be removed unless a block to migrating adult spawners or impairment of water quality can be demonstrated.

34. **Everest, F.H. and W.R. Meehan.** Some Effects of Debris Torrents on Habitat of Anandromous Salmonids. In Measuring and Assessing the Effectiveness of Alternate Forest Management Practices on Water Quality. National Council of Paper Industries for Air and Stream Improvement, Tech. Bull. 356: 23-30.

35. **Frear, S.T.** 1982. Ecological Benefits of Large Organic Debris in Streams. USDA Forest Service, Forestry Research West. February: 7-10.

In small streams, large organic debris is the principal factor determining both their biological and physical characteristics. Large debris in streams increases the "roughness" of the stream channel, causing sediment and organic matter to be trapped and slowing its movement through the stream system. Often the large debris creates a stepped stream profile, with stream energy dissipated in relatively short, steep sections of the channel.

Debris in streams also creates habitat for aquatic organisms both by serving as a substrate in the streambed and by modifying streamflow to form areas where material is deposited.

Removal of large debris may reduce long-term productivity and increase the rate of sediment movement from headwater streams to the main river system.

36. **Froehlich, H.A.** 1975. Accumulation of Debris in Forest Streams Before and After Logging. In Logging Debris in Streams, notes for a workshop. Extension Service and Dept. of Forest Engineering, Oregon State University, Corvallis, Oregon, September 9-10, 10p.

Observations on the natural debris loads in 17 drainages are reported and the accumulation and transport of this material is discussed. The effect of timber falling and yarding on the total coarse and fine debris was followed on ten of these streams. The differences in debris loading produced by conventional timber falling, a cable-assist falling method and three width of buffer strips are discussed.

37. **Gibbons, D.R., et al.** 1990. Fish in the Forest: Large Woody Debris in Streams A New Management Approach to Fish Habitat. USDA Forest Service, R10-MB-86. Alaska Region, Juneau, Alaska. 20p.

All five species of Pacific salmon (chinook, coho, sockeye, pink, and chum), steelhead and cutthroat trout, and Dolly Varden char occur in freshwater streams of southeast Alaska. These fish, which belong to the salmonid family, generally require two types of fresh water habitat: (1) spawning habitat, where eggs are deposited and incubated, and (2) rearing habitat, where young fish live before migrating to the sea. Pink salmon and chum salmon are the exceptions; these species spawn in streams but their fry move to the ocean soon after hatching. Coho, chinook (king), and sockeye salmon, the trouts, and Dolly Varden char live in the stream for one or more years before migrating to the sea: the quantity and quality of rearing habitat available greatly affect their survival.

Many people believe streams should be free from debris, crystal clear, and bubbling over gravel and boulders. To the casual observer, a stream covered with stacks of crisscrossed logs appears to be unnatural and undesirable. Fallen trees and other large pieces of wood do, however, significantly shape the stream channel, provide an energy base (nutrients), and influence the composition of fish species and quality of fish. Fish need woody debris; it is as much a natural part of their stream habitats as are boulders and water.

Large woody debris is an important component of the stream habitat of salmon, trout, and char. It can be either beneficial or detrimental.

Benefits are:
Provides cover for fish
Provides protection for spawning adults from predators
Creates pools
Increases habitat diversity for fish and aquatic insects
Aids fish migration during periods of low water
Improves access in high-velocity stream sections by creating "channel-stepping" pools
Traps gravel that can be used for spawning habitat
Traps sediments and slowly releases it downstream
Creates diverse stream velocity patterns
Forms a nutrient base for stream organisms that eventually become fish food
Deflects streamflow, which creates undercut banks and channel diversity
Stabilizes streambanks.

Although woody debris accumulations can have detrimental effects, these are generally temporary and are far outweighed by beneficial aspects. Debris management is not a simple task: it is neither a case of removing all debris nor of adding it indiscriminately. A continuous source of woody debris should be provided to the stream environment, through a controlled management program.

38. ____________**, and E.O. Salo.** 1973, An Annotated Bibliography of the Effects of Logging on Fish of the Western United States and Canada. USDA Forest Service Gen. Tech. Rep. PNW-10. Pacific Northwest Forest and Range Experimental Station, Portland Oregon. 145p.

This bibliography is an annotation of the scientific and nonscientific literature published on the effects of logging on fish and aquatic habitat of the Western United States and Canada. It includes 278 annotations and 317 total references. Subject areas include erosion and sedimentation, water quality, related influences upon salmonids, multiple logging effects, alteration of streamflow, stream protection, multiple-use management, streamside vegetation, stream improvement, and descriptions of studies on effects of logging. A review of the literature, a narrative on the state of the art, and a list of research needs determined by questionnaires are included.

39. **Grant, G.E.** 1986. Downstream Effects of Timber Harvest Activities on the Channel and Valley Floor Morphology of Western Cascade Streams. Ph.D. Thesis, John Hopkins University, Baltimore, Maryland 364p.

40. __________ 1987. Assessing the Effects of Peak Flow Increases on Stream Channels: A Rational Approach. p. 142-149. In R.Z. Callaham and J.J. DeVries (Tech. Coords.): Proceedings: California Watershed Management Conference, Nov. 18-20, 1986, West Sacramento, California. Wildland Resources Center Report No. 11. University of California, Berkeley, California.

Current methods for assessing cumulative watershed effects of forest practices employ arbitrary limits on the percentage of basin drainage area affected within certain time periods. Data to support such limits are sparse, making these management strategies questionable. A more defensible procedure uses the magnitude of flow increase that can be accommodated by downstream channels before channel instability occurs. For a given channel cross-section and particle size distribution of bed material, the effective discharge required to entrain bed material of a particular size can be calculated and referred to a discharge to determine the allowable increase in flow. This, in turn, can be used to set the upper limit on total basin compaction area. An example of this procedure demonstrates that streams with different channel geometries and bed materials have different intrinsic sensitivities to peak flow increase.

41. __________ 1988. The RAPID Technique: A New Method for Evaluating the Effects of Forest Practices on Riparian Zones. USDA Forest Service, Gen. Tech. Rep. No. PNW-220. Pacific Northwest Research Station, Portland, Oregon. 36p.

The RAPID (riparian aerial photographic inventory of disturbance) technique is a method for using measurements made on aerial photographs of patterns of riparian canopy disturbance to evaluate changes in channel conditions through time and to link such changes with their possible upstream causes. The RAPID technique provides resource specialists and managers with a relatively quick way of identifying stream reaches that are chronically or recently disturbed by a variety of channel processes, including increased peak flows and sedimentation from point and non-point sources. With examples from western Oregon, this paper describes how to apply the RAPID technique and analyze the results to evaluate downstream or cumulative effects of forest practices.

42. __________**, M.J. Crosier, and F.J. Swanson.** 1984. An Approach to Evaluating Off-Site Effects of Timber Harvest Activities on Channel Morphology. p. 177-186. In C. O'Loughlin and A. Pearce (eds.): Proceedings: Symposium on the Effects of Forest Land-use on Erosion and Slope Stability, May 7-11, 1984, Honolulu, Hawaii. East-West Center, University of Hawaii, Honolulu, Hawaii.

We present a methodology and develop a new quantitative, aerial photograph interpretation technique for assessing channel response to various off-site effects associated with timber harvest activities. The degree of channel enlargement, associated with a 100-year storm event in the Oregon western Cascades, is strongly related to upstream logging activities. The nature of the response relates to the mechanism by which sediment and water are introduced to the stream. Of the five types of initiation site (axial landslide, riparian landslide, forest growth, clearcut, and road) for channel enlargement, axial landslides were overwhelmingly important in their occurrence and influence.

43. __________**, F.J. Swanson, and M.G. Wolman.** Pattern and Origin of Stepped-Bed Morphology in High-Gradient Streams, Western Cascades, Oregon. submitted to: Geol. Soc. of Am. Bull. 102: 340-352.

A general hierarchical framework for viewing stepped-bed morphology in high-gradient channels is presented. we emphasize channel units - bed features that are one or more channel widths in length - as a particularly important scale of variation. Field studies in two streams in the Cascade Range in Oregon indicated that pool, riffle, cascade, and step channel units had distinct bed slope ranges, with average slopes of 0.005, 0.011, 0.029, 0.055, and 0.173, respectively. Steeper units (rapids and cascades) are composed of step pool sequences created by particles representing the 90th or larger percentile size fraction of bed material. Step spacing is inversely proportional to bed slope.

The distribution of channel units along the stream is influenced by bedrock and processes that introduce coarse sediment .Cascade and pool units dominate where landslide and debris-flow deposits constrict the channel width and deliver large immobile boulders to the channel, whereas riffle and rapid units dominate in broad valley flats where deposition of finer sediments occurs. Markov chain analysis indicates that channel units occur in non random two-unit sequences with the slope of the upstream unit inversely proportional to the slope of the next downstream unit. Pool-to-pool spacings average two to four channel widths, but variability in spacing is high, owing to uneven distribution of bedrock outcrops and boulder deposits within the channel.

Hydraulic reconstruction indicates that channel units form during high-magnitude, low-frequency events with recurrence intervals of about 50 yr. Comparison of channel unit morphology to high-gradient flume experiments with heterogeneous bedload mixtures indicate that unit morphogenesis is linked to factors that cause congestion of large particles during bedload transport events; these include local constrictions in channel width, immobile bed material, and abrupt fluctuations in velocity due to hydraulic jumps that promote deposition. Channel units appear to be a two-dimensional bar form found in streams where gradients exceed 2%, bedload is widely sorted, and width-to-depth ratios and sediment supply are low - conditions found in many mountain environments.

44. **Gregory, K.J. and A.M. Gurnell.** 1988. Vegetation and River Channel Form and Process. p. 11-43. In H.A. Viles (ed.): Biogeomorphology. Basil Blakewell Ltd.

In this chapter it is argued that it is now timely for more coordinated consideration of the significance of vegetation upon river channel form and process, and that this is a necessary prerequisite for the further development of river management procedures.

Vegetation influences the supply of water and sediment to the river channel network; the morphology of river channels; and the routing of water and sediment through the network of river channels. An understanding of these influences can assist our interpretation of past river behaviour. Examples have been provided to indicate how recent research is clarifying the intricate way in which vegetation is encompassed within the pattern of variables in the drainage basin system.

In viewing the ecological component of the fluvial system it is important to think of the instream uses. Factors controlling such instream uses have been reviewed, and relationships with discharge discussed. Thus in future management of rivers it is not only important to think of vegetation and the effect that it has directly and indirectly upon river behaviour, but also to think of the ways in which river management can provide habitats for fauna and particularly for fish in the river environment.

45. **Gregory, K.J., A.M. Gurnell, and C.T. Hill.** 1985. The Permanence of Debris Dams Related to River Channel Processes. Hydrol. Sci. 30: 371-381.

Vegetation debris dams occur on average every 27 m of channel in a drainage basin in the New Forest, Hampshire, England, and within less than 12 months 36% changed position or were destroyed and 36% changed character. Such dams significantly affect the timing of flood peaks as they are routed through the channel network; their significance has been demonstrated by preliminary analysis of hydrograph travel times by measurements in a reach at different flow stages, and by measurements before and after dam clearance. There was a difference in travel time of over 100 minutes for the situation with and without dams for a discharge of 0.1 m^3s^{-1} but a difference of only 10 minutes for a discharge of 1.0 m^3s^{-1} along the same 4028 m channel reach.

46. **Grette, G.B.** 1985. The Role of Large Organic Debris in Juvenile Salmonid Rearing Habitat in Small Streams. M.Sc. Thesis, University of Washington, Seattle. 105p.

The intent of this study was to determine long-term trends in abundance of large organic debris (LOD) in small streams, and to examine changes in juvenile salmonid rearing habitat resulting from changes in abundance of LOD. Twenty- eight 100 m sites on small (drainage area: 3.4 to 12.4 km^2) low-gradient (0.5 to 2.0%) streams in the western Olympic Peninsula of Washington were studied. Seven sites were assigned to each of four groups based on logging history of the streamside forest: 1) unlogged, 2) young second-growth (logged 10-26 years ago), 3) middle-aged second-growth (logged 27-39 years ago) and, 4) old second-growth (logged 40-62 years ago).

Old growth LOD was more abundant in the unlogged group (ave. 59.9 pieces, 78.1 m^3) than in the young (ave. 33.7 pieces, 40.6 m^3), middle aged (ave. 22.6 pieces, 33.7 m^3), or old (ave. 22.0 pieces, 46.1 m^3) second-growth groups. The second-growth sites also differ with respect to abundance of old-growth LOD; linear regression of numbers of pieces of old-growth LOD and years since logging occurred yields a slope (or loss rate) of about 0.5 pieces of LOD per 100 m of lineal stream channel per year. Second-growth LOD accumulates in these channels very slowly and is not significant until about 50-60 years after logging.

Recruitment of second-growth debris from these second-growth forests was insufficient to offset natural and logging-related losses of LOD. Management of streamside forests to provide LOD for streams or manipulation of debris levels is necessary to prevent long-term declines in abundance of LOD.

LOD provided more (not statistically significant $p > .05$) instream cover (ave. 27.9 m^2) and overstream cover (44.9 m^2 at summer low-flow in the unlogged group than in the young (ave. 25.2 m^2, 27.4 m^2) middle-aged (ave. 15.9 m^2, 21.4 m^2), or old (ave. 15.8 m^2, 30.3 m^2) second-growth groups.

Densities of steelhead (1+) and cutthroat (1+ and older) in individual pools were correlated ($p \leq .05$) with area of cover at summer low-flow. Numbers of steelhead and cutthroat (1+ and older) were correlated with area of cover during the winter. Densities of coho fry were not correlated ($p > .05$) with area of cover at summer low flow. Coho fry were observed to be closely associated with cover provided by LOD during winter.

47. **Gurnell, A.M. and K.J. Gregory.** 1984. The Influence of Vegetation on Stream Channel Processes. p. 515-535. In Burt T.P. and D.E. Walling (eds.): Catchment Experiments in Geomorphology. Geo Books, Norwich, UK.

48. **Hall, J.D. and C.D. Baker.** 1977. Biological Impact of Organic Debris in Pacific Northwest Streams. In Logging Debris in Streams Workshop. Oregon State University Press, Corvallis, Oregon, 13p.

49. **Harmon, M.E., et al.,** 1986. Ecology of Coarse Woody Debris in Temperate Ecosystems. p. 133-302. In A. Macfadyen and E.D. Ford (eds.): Advances in Ecological Research 15. Academic Press, London - New York.

Coarse woody debris (CWD) is an important component of the temperate stream and forest ecosystems. We have reviewed the rates at which CWD is added and removed from the ecosystems, the biomass found in the streams and forests, and many functions that CWD serves.

CWD is added to ecosystems by numerous mechanisms, including wind, fire, insect attack, pathogens, competition, and geomorphic processes. Despite the many long-term studies on tree mortality, there are few published rates of CWD input on mass-area^{-1} time^{-1} basis. Most ecological studies have not measured CWD input over a long period or a large enough area to give accurate estimates. Input rates measured in temperate ecosystems range from 0.12 to 14.9 Mg ha^{-1} year^{-1} and vary greatly over time and space.

Once CWD enters the detrital food web, it is decomposed by a large array of organisms and physical processes. Although respiration-caused losses have been the focus of many studies, CWD is also significantly transformed physically and chemically. Movement of CWD, especially in streams, is also an important but poorly documented mechanism whereby CWD is lost from ecosystems. Many factors control the rate at which CWD decomposes, including temperature, moisture, the internal gas composition of CWD, substrate quality, the size of the CWD, and the types of organisms involved. However, the importance of many of these factors has yet to be established in field experiments.

The mass of CWD in an ecosystem ideally represents the balance between addition and loss. In reality, slow decomposition rates and erratic variations in input of CWD cause the CWD mass to deviate markedly from steady-state projections. The mass of CWD in stream and forest ecosystems varies widely, ranging between 1 and 269 Mg ha^{-1}. Many differences correspond to forest type, with deciduous-dominated systems having generally lower biomass than conifer-dominated systems. However, conifer-dominated systems with low productivity also have low CWD mass. Stream size also influences CWD mass in lotic ecosystems, while successional stage dramatically influences CWD mass in both aquatic and terrestrial settings.

CWD performs many functions in ecosystems, serving as autotrophic and heterotrophic habitat and strongly influencing geomorphic processes, especially in streams. It is also a major component of nutrient cycles in many ecosystems. We have reviewed these many functions and conclude that CWD is an important functional component of stream and forest ecosystems.

Humans have greatly affected the amount of CWD found in temperate ecosystems by removing CWD and by changing the rate of input and the rate and pattern of loss. In some cases, human influences have been so pervasive that natural conditions are difficult to define. Management practices concerning CWD often have not been based on the numerous beneficial roles this material plays in ecosystems. Better scientific understanding of these functions and the natural factors influencing CWD dynamics should lead to more enlightened management practices.

50. **Heede, B.H.** 1972a. Influences of a Forest on the Hydraulic Geometry of Two Mountain Streams. Water Res. Bull. 8: 523-530.

The influence of a forest on the formation of steps in two small streams of the Colorado Rocky Mountains was studied. Steps provided by logs fallen across the channel added to flow energy reduction. The streams required additional gravel bars to adjust to slope. Average step length between logs and gravel bars was strongly related to channel gradient and median bed material size. Based on the average number of log steps per 50 feet of channel, an average of 116 percent of gravel bars were added at Fool Creek and 60 percent at Deadhorse Creek. The latter had 52 percent more logs in the channel and therefore required less bed material movement than the former. Although these are "rushing mountain streams," most flow velocities ranged between 0.5 and 2.5 f.p.s. Exponents of a function relating rate of change of depth or velocity to discharge indicated that dynamic stream equilibrium was attained. Implications for forest management are that sanitation cuts (removal of dead and dying trees) would not be permissible where a stream is in dynamic equilibrium and bed material movement should be minimized.

51. __________ **1972b. Flow and Channel Characteristics of Two High Mountain Streams. USDA Forest Service, Res. Pap. No. RM-96. Rocky Mountain Forest and Range Experimental Station, Fort Collins, Colorado. 12p.**

Detailed investigations of the longitudinal profiles showed that a great number of gravel bars and logs crossed the channel. The logs accumulated gravel and thus formed steps. Since step spacing between the logs did not change within individual channel reaches, the remaining adjustment to the streams slope was achieved by gravel bar formation. Step length decreased with increasing channel gradient and increasing median bed material size. The cumulative height of steps formed by logs and gravel bars nearly offset the total fall of Deadhorse Creek, and approached 75 percent of the fall of Fools Creek. Bars and logs together provided an average of 7.7 and 5.4 energy dissipators for 50 feet of channel. Combined with the roughness of the gravel, as well as other hydraulic components such as discharge, width, and slope, these energy dissipators led to relatively low velocities; most values ranged between 0.5 and 2.5 f.p.s. The average channel gradients of the reaches of the "rushing mountain streams" were 0.08 and 0.22.

Within the range of flows experienced during the study, energy dissipation due to gravel and log steps as well as roughness of gravel beds and rock outcrops increased with decreasing discharge.

The study shed some light on the influence of streamside forests on the formation of steps in small mountain channels. It was shown that the streams required additional gravel bars to adjust to slope.

Forest management implications of gravel bar-log step relationship appears to be that sanitation cutting (removal of dead and dying trees) should not be practised along small mountain streams at dynamic equilibrium; the movement of bed material in such streams should be minimized. Such equilibrium is necessary, for instance, for maintenance of spawning beds for fish.

52. __________ **and J.N. Rinne.** 1990. Hydrodynamic and fluvial Morphologic Processes: Implications for Fisheries Management and Research. North Am. Jour. of Fish. Man. 10: 259-268.

Past work has not sufficiently integrated the sciences of hydrology and fisheries. Therefor, streamflow, sediment transport, and channel morphology between physical and biological (fishery) processes. These three physical factors (and certainly others) dictate both habitat quantity and quality for different life stages of fishes, and their inclusion in habitat assessments will enhance the quality of investigations. Interaction of the hydraulic and morphologic factors creates either dynamic equilibrium or disequilibrium. Indicators are given for determining the type of equilibrium condition.

Thus, stream reaches in disequilibrium can be avoided for enhancement or channel stabilization projects. Neglect of the equilibrium condition increases the probability of failure of enhancement projects. Examples of enhancement measures and possible failures are described. Investigators are also urged to use additional hydrodynamic parameters, such as the Froude or Reynolds number, to quantify objectively the type of flow for improved mathematical-statistical analysis of fish-flow relationships. Land managers and researchers are encouraged to design future projects to improve our understanding of the very complex interactions between fish and their hydraulic and morphologic environment. Characteristics of fish habitat must be modified with great care, and then only if (1) the causes for an undesirable condition are known and (2) the measures will be compatible with future stream development. In such an evaluation of fish habitat, the inclusion of hydrodynamic and fluvial morphologic variables should provide more precise quantification of habitat characteristics.

53. **Heimann, D.C.** 1989. Recruitment Trends and Physical Characteristics of Coarse Woody Debris in Oregon Coast Range Streams. M.Sc. Thesis. Oregon State University, Corvallis, Oregon. 121p.

This study investigates the long-term consequences of timber stand removal on the recruitment, physical characteristics, and spatial distribution of coarse woody debris in small (second- and third-order) streams of the Oregon Coast Range. A chronosequence of stream-stand systems, ranging from 21- to 140-years since disturbance (YSD), were sampled to determine temporal trends in coarse woody debris characteristics along with successional changes in riparian forests.

Total debris volumes range from 135 to 864 cubic meters per hectare. No distinct trend was found in the total volume of debris over time because of the variable effects of the disturbance event on per-disturbance debris volumes (debris delivered prior to or during the disturbance event). Post-disturbance deliveries (debris delivered after disturbance by second growth stand) of deciduous debris increased through 65-YSD then decreased. Post-disturbance coniferous debris volumes, which were first detected at the 28-YSD site, increased from 28-to 140-YSD. Per-disturbance coniferous debris comprised the largest proportion of the total volume in the stream system until approximately 122-YSD at which time post-disturbance coniferous debris made up the largest proportion of total debris volume.

At all sites the largest volume of pre-disturbance debris volumes were in the large (greater than 0.03 meters) diameter size class while the largest proportion of post-disturbance debris volumes were in the large diameter class only at the 65- through 140-YSD sites. The largest proportion of pre-disturbance debris volumes were in the large (greater than 4.0 meters) length size class at the 28-through 140-YSD sites and the largest proportion of post-disturbance debris was in the large size class at the 28- through 140-YSD sites.

Morisita's index of dispersion, I, was used to test the type of spatial distribution pattern followed by the debris pieces. Results indicated that debris pieces in the pre- and post-disturbance delivery classes along with total pieces tended to follow a contagious (clumped) spatial distribution pattern at all sites.

Results from this study will provide an improved perspective of the long term forest stand and coarse woody debris dynamics associated with riparian areas.

54. **Helmers, A.E.** 1966. Some Effects of Log Jams and Flooding in Salmon Spawning Streams. USDA Forest Service Res. Note NOR-14. Inst. of Northern Forestry, Northern Forest Experimental Station, Juneau, Alaska. 4p.

Streambed scouring and deposition occurred in the areas of two constructed log-debris jams. Gravel shifting associated with jams and flood flows reduced the fine material content of the streambed gravel and may have been responsible for the increased dissolved oxygen concentration.

Log-debris jams intensify streambed instability, especially during floods. They may reduce salmon production in otherwise favourable areas. Gravel movement presumably reduces egg and larvae survival. On the other hand, loss of fine material because of gravel movement should benefit the salmon development environment by improving intergravel waterflow, thus increasing dissolved oxygen availability and making possible more effective removal of metabolic wastes. The effect of log-debris jams on salmon production remains undetermined. From a conservative viewpoint, however, temporary or unstable jams are judged to be detrimental.

55. **Hickin, E.J.** 1984. Vegetation and River Channel Dynamics. Can. Geog. 28(2): 111-126.

The physical science of fluvial geomorphology is flawed because it ignores processes that are not easily quantifiable and physically or statistically manipulable. The influence of vegetation on river behaviour and fluvial geomorphology is a set of these processes. Vegetation may exert significant control over fluvial processes and morphology through five mechanisms: flow resistance, bank strength, bar sedimentation, formation of log-jams, and concave-bank bench deposition. Examples of these mechanisms, largely drawn from the Squamish River in British Columbia, are presented, and implications for future research are briefly discussed.

56. **Hogan, D.L.** 1985. The Influence of Large Organic Debris on Channel Morphology in Queen Charlotte Island Streams. p. 263-295. In Proceedings: Western Assoc. Fish and Wildlife Agencies, 1984.

57. __________ 1986. Channel Morphology of Unlogged, Logged and Torrented Mountain Streams in the Queen Charlotte Islands. Land Management Rpt. No. 49. Ministry of Forests, Province of British Columbia, Victoria, B.C. 94p.

This study compares the morphology of coastal, gravel-bed streams in two logged, one logged and debris torrented, and two unlogged watersheds in the Queen Charlotte Islands. The influence of both logging and direct mass wasting event on channel morphology and, consequently, on the in-stream physical habitat of salmonids is quantified. The comparison also provides a basis for determining habitat rehabilitation criteria for damaged channels. Pools and riffles are discussed in detail.

Longitudinal profiles of long channel segments indicated that channels in watersheds either logged to the channel banks by old techniques (but not torrented), or logged by more recent methods (but which have experienced direct mass wastage events) result in reduced pool-to-pool spacings, increased riffle heights, and altered pool depths. Increases in stored sediment volumes produce proportionally larger riffles and smaller pools, thus reducing available rearing habitat. No significant differences in pool and riffle characteristics were found between unlogged watersheds and those logged by contemporary techniques and not torrented.

Large organic debris (LOD) appeared to be a major influence on stream morphology. A comparison of reaches indicated that LOD characteristics were altered in older logged and torrented channels, including a shift in the LOD size distribution, with smaller in-channel material being more prevalent. Orientation of material was also altered: more LOD lay parallel to the flow direction, as opposed to the more common diagonal orientation found in unlogged and non-torrented channels. This shift in orientation was responsible for a reduction in channel width and depth variability, reduced sediment texture variability, fewer cut banks, smaller pool areas, and decreased channel stability. These changes resulted in reduced habitat diversity and quality. No morphological differences were detected between unlogged and recently logged (non-mass wasted) reaches.

Results of this study suggest that the architecture of unlogged channels can be duplicated to help rehabilitate streams damaged by mass wasting. LOD should play a major role in rehabilitation, and several recommendations for channel restoration are made.

58. __________ 1987. The Influence of Large Organic Debris on Channel Recovery in the Queen Charlotte Islands, British Columbia, Canada. p. 343-353. In R.L. Beschta et al. (eds.): Proceedings: Erosion and Sedimentation in the Pacific Rim Symposium. International Assoc. of Hydrol. Sci. August, 1987, Corvallis, Oregon. IAHS Publication 165. Wallingford, Oxfordshire, U.K.

In-stream LOD characteristics are evaluated in unlogged and logged coastal watersheds. The study examines the input, storage and output components of LOD budgets, how these are altered in logged and torrented channels and how these changes influence the recovery of disturbed channels. In small and medium sized watersheds, all components of the LOD budget are altered after logging and debris torrenting. Initially, the size and abundance of debris staged to enter the stream system are reduced. Reduction in material size leads to a shift in the orientation of debris stored within the channel zone. Consequently, the scouring and trapping functions of debris pieces are altered. A less complex morphology results, including reduced depth, width and sediment texture variability and diminished pool area. The smaller debris is less stable causing an increased tendency for the material to cluster into major debris jams; this stores large volumes of clastic sediment upstream and leads to reduced channel stability. Because logging and debris torrenting can affect streambank vegetation for long periods of time, it is possible that the resultant channel disturbances will not be reversed over forest management time scales.

59. _________ **and M. Church.** 1989. Hydraulic Geometry in Small, Coastal Streams: Progress Toward Quantification of Salmonid Habitat. Can. J. Fish. Aquat. Sci. 46: 844-852.

It is difficult to quantify in-stream physical attributes of salmonid habitats, yet quantification is necessary if conditions are to be compared within or between streams over time or space. This paper presents an objective method based on hydraulic geometry to quantify hydraulic characteristics of fish habitat. Two small streams in coastal British Columbia provide examples. Morphological mapping and stream flow measurements were used to generate the bivariate distributions of mean depth and mean velocity at cross sections within the study reaches at various discharge. The distributions are used to generate measures of potentially usable area within the streams. Survey criteria and numerical adjustments are presented to improve comparability between channels. The streams respond similarly to a change in discharge. The main hydraulic difference is a decrease in area useful to coho salmon (Oncorhynchus kisutch) for rearing at high discharges in Bonanza Creek (Logged) compared with Hangover Creek (unlogged). The example indicates that quantitative comparisons can be made, at comparable flows, between reaches and between streams, or over time.

60. **House, R.A. and P.L. Boehne.** 1986. Effects of Instream Structures on Salmonid Habitat and Populations in Tobe Creek, Oregon. North Am. Jour. of Fish. Man. 6: 38-46.

Tobe Creek, Oregon, was studied in 1982 and 1983 to compare physical and biological differences between a young-alder stream section logged and cleaned of large debris 20 years ago and a mature mixed-conifer section unlogged and containing large amounts of woody debris . Stream enhancement techniques were used in 1982 to simulate large woody debris in the logged alder section to try to increase salmonid use. Large woody debris in the channel caused the development of secondary channels, meanders, pools, and undercut banks in the unlogged, mature-conifers, stream section. These elements were noticeably missing in the young-alder section. The mature-conifer section had more than twice as many pools and 10 times the amount of spawning gravel compared to the young-alder section. Salmonid biomass was significantly greater in the mature-conifer than in the young-alder section prior to stream enhancement; after enhancement, no significant difference was found. Prior to enhancement, three times as many coho salmon (Oncorhynchus kisutch) and trout fry (cutthroat trout and steelhead) were living in the mature-conifer stream section. There was a positive correlation between coho salmon numbers and the presence of large woody debris. The study revealed that structure is most likely a more important factor than shade in governing a stream's capacity for producing salmonids.

61. **House, R.A. and V. Crispin.** 1990. The Economic Analysis of the Value of Large Woody Debris as Salmonid Habitat in Coastal Oregon Streams. BLM-OR Tech. Note #7. Bureau of Land Management, Portland, Oregon.

62. **Kaufmann, P.R.** 1987. Channel Morphology and Hydraulic Characteristics of Torrent- Impacted Forest Streams in the Oregon Coast Range, U.S.A. Ph.D. Thesis. Oregon State University, Dept. Forest Engineering, Corvallis Oregon, 235p.

Tracer derived estimates of hydraulic resistance and transient hydraulic storage were related to measures of pool volume and channel morphometric variability in small streams of the Oregon coast, U.S.A. Fourteen 100 m study reaches in 3 streams were selected to compare channel and hydraulic characteristics in streams representing a time series of recovery since major torrent scour or deposition (2, 12 and 120 years). Transient storage ("dead zone") volume fractions, ranging from 0.3 to 0.6 in the study reaches, were significantly ($p <.01$) correlated with aggregate residual pool volume ($r = +0.94$) and the standard deviation of thalweg depth ($r = +0,95$). Darcy-Weisbach friction factors (f) ranging from 2 to 90 were correlated (r values from +0.95 to +0.98) with the standard deviation of thalweg depth (SDD) within restricted ranges of summer low flow and elevated springtime discharge. Regressions of F versus SDD for combined data collected over a range of discharges (0.019 to 0.11 m^3/s) showed increased scatter. A semi-logarithmic relationship ($r^2 = 0.60$, $n = 40$) between dimensionless velocity $(8/f)^{0.5}$ and a dimensionless measure indexing relative submergence of large scale bed features (mean thalweg depth/SDD) was significant at $p <.01$.

Measures and indices of pool volume and transient storage were positively correlated ($r = +0.78$ to $+0.89$) with volumetric loadings of woody debris. High total pool and dead zone volumes in reaches were largely due to plunge pools formed by scouring downstream of woody debris accumulations. Among the study streams, the greatest reach pool volume and channel complexity occurred in torrent deposit reaches of the immediate (12 yr.) recovery stage stream. Reaches scoured recently (2 yr.) by a debris torrent had the lowest pool volume and channel complexity. The stream experiencing The longest period of "recovery" (120 yr.) had characteristics between those of the 2- and 12-year recovery streams. Torrent scouring reduced pool volume, dead zone fraction and channel morphometric variability. Torrent deposition and subsequent local reworking of sediments by the stream increased values of these variables, especially when torrent deposits contained woody debris and boulders.

The relative importance of pool- forming agents varied with recovery time and amount of torrent deposits. Bedrock, cobbles, log clusters, and single logs contributed about equally to the small residual pool volume in reaches recently scoured by a torrent. Log clusters and boulders dominated in two reaches of the intermediate recovery class stream where logs and sediment were deposited by a torrent, and in two reaches where boulders were left as lag deposits. Bedrock and log clusters contributed about equally to pool formation in the undisturbed stream.

63. **Keller, E.A., A. MacDonald, and T. Tally.** 1981. Streams in the Coastal Redwood Environment: The Role of Large Organic Debris. p. 161-176. In R.N. Coats (ed.): Proceedings: Symposium on Watershed Rehabilitation in Redwood National Park and Other Coastal Areas. Binghampton, NY., Sept. 21-22, 1979, Kendal/Hunt Pub. Co.

Large organic debris (greater than 10 cm in diameter) has a major control on channel form and process (and thus anadromous fish habitat) in streams of the coastal redwood environment. Several lines of evidence support this conclusion: first, large organic debris may reside in the stream channel for centuries and, therefore, is a permanent part of the fluvial system; second, large organic debris exerts considerable control over channel morphology, particularly in the development of pools; third, large organic debris produces numerous sediment storage sites, supporting a

sediment buffer system that modulates the routing of sediment through the fluvial system; and fourth, large organic debris in steep streams significantly effects the way potential energy is expended by concentrating energy expenditure over short reaches where organic steps or other accumulations of debris exist.

Large organic debris in streams is pertinent to two interrelated management problems in northwestern California: restoration and enhancement of anadromous fish habitat, and reduction of sediment pollution. Management of streams to maximize production of anadromous fish in the coastal redwood environment should consider the entire fluvial system, including the role of large organic debris. Large organic debris in unusually large amounts may block fish migration and cause adverse channel erosion. However, within limits, large organic debris is probably necessary for many streams sustaining anadromous fisheries. Therefore, stream clearing operations must carefully weigh the benefits of locally stabilizing stream banks, opening up stream anadromous fish habitat, or marketing merchantable timber with potential dangers in losing hydrologic variability and mobilizing large quantities of sediment stored in conjunction with large organic debris.

64. **__________, W.N. Melhorn, and M.C. Gardner.** 1976. Effects of Autodiversion (Logjams) on Stream Channel Morphology. Abstracts with Programs: Geol. Soc. Am. 8(6): 950.

Formation of logjams in meandering streams is associated with: 1) erosional processes that locally increase channel width by more than 50 percent as water is diverted around an obstruction; 2) depositional processes that initiate the development of mid-channel bars as islands immediately downstream from a logjam; and 3) a backwater effect upstream and localized scour adjacent to the logjam.

Investigation of logjams in the midwestern and southeastern United States suggests that they may be intimately associated with the development of short, braided stream reaches and meander cutoffs that resemble but are distinctly different from chute cutoffs. Mapping of recent logjams in a stream establishes morphologic criteria (bank erosion and associated island development) used to recognize sites of former logjams. Dendrochronology is used where possible to date islands that developed in response to logjams no longer present in the channel.

Autodiversion of a stream channel by a logjam which ponds water and locally increases overbank flow may facilitate the development of a meander cutoff provided: (1) the jam is in a favourable location on the bend; and (2) a favourable flood plain drainage system exists to concentrate the diverted water across the meander bend. Furthermore, the chance of

a cutoff is dependent upon the size of the stream. Large rivers rarely have logjams and in very small streams trees tend to bridge rather than block the channel. Therefore, the most favourable conditions for a cutoff to develop in association with a logjam occur with an intermediate size stream. The time during which a cutoff develops in a few tens of years and may be in response to the formation of several logjams in the same vicinity over that period of years.

65. __________, **and F.J. Swanson.** 1979. Effects of Large Organic Debris on Channel Form and Fluvial Processes. Earth Surface Processes 4: 361-380.

Stream channel development in forested areas is profoundly influenced by large organic debris (logs, limbs and rootwads greater than 10 cm in diameter) in the channels.

In low gradient meandering streams large organic debris enters the channel through bank erosion, mass wasting, blowdown, and collapse of trees due to ice loading. In small streams large organic debris may locally influence channel morphology and sediment transport processes because the stream may not have the competency to redistribute the debris. In larger streams flowing water may move large organic debris, concentrating it into distinct accumulations (debris jams). Organic debris may greatly affect channel form and process by: increasing or decreasing stability of stream banks; influencing development of midchannel bars and short braided reaches; and facilitating, with other favourable circumstances, development of meander cutoffs.

In steep gradient mountain streams organic debris may enter the channel by all the processes mentioned for low gradient streams. In addition, considerable debris may also enter the channel by way of debris avalanches or debris torrents. In small to intermediate size mountain streams with steep valley walls and little or no floodplain or flat valley floor, the effects of large organic debris on the fluvial processes and channel form may be very significant. Debris jams may locally accelerate or retard channel bed and bank erosion and/or deposition; create sites for significant sediment storage; and produce a stepped channel profile, herein referred to as "organic stepping", which provides for variable channel morphology and flow conditions.

The effect of live or dead trees anchored by rootwads into the stream bank may not only greatly retard bank erosion but also influence channel width and the development of small scour holes along the channel beneath tree roots. Once trees fall into the stream, their influence on the channel form and process may be quite different than when they were defending the banks, and, depending on the size of the debris, size of the stream, and many other factors, their effects range from insignificant to very important.

66. **__________, and T. Tally. 1979. Effects of Large Organic Debris on Channel Form and Fluvial Processes in the Coastal Redwood Environment. p. 169-197. In D.D. Rhodes and G.P. Williams (eds.): Proceedings: Adjustments of the Fluvial System, Tenth Annual Geomorphology Symposium. State University of New York, Binghampton. Kendal-Hunt, Dubuque, Iowa.**

Large organic debris in streams flowing through old-growth redwood forests in California significantly influence channel form and fluvial processes in small to intermediate size streams. The role of large organic debris is especially important in controlling the development of the long profile and in producing a diversity of channel morphologies and sediment storage sites. The residence time for the debris in the channel may exceed 200 years.

The total debris loading along a particular channel reach represents a relation between rates of debris entering and leaving the reach. Loading is primarily a function of such interrelated variables as geology, valley-side slope, landslide activity, channel width, discharge, and upstream drainage area. Generally there is an inverse relationship between debris loading and stream size.

Large organic debris in steep mountain streams may produce a stepped-bed profile where a large portion of the stream's potential energy loss for a particular reach is expended over short falls or cascades produced by the debris. Approximately 60% of the total drop in elevation over a several hundred meter second-order reach of Little Lost Man Creek is associated with large organic debris. The debris also provides numerous sites for sediment storage. Stored sediment covers up to about 40% of the entire area of the active channel in the study sections. The sediment storage sites or compartments provide an important buffer system that regulates the bedload discharge.

The influence of large organic debris on channel form and process in low gradient stream reaches is less than in steeper channels. However, the debris still may affect development of pools and may help stabilize the channel banks. Root mats may armour banks and provide important fish habitats in the form of undercut banks. The stream channel of some low gradient reaches of Prairie Creek, California, may be quite stable. Lateral migration has only been one to two channel widths in the last several hundred years.

Management of streams in the coastal redwood environment so as to minimize adverse effects while maximizing anadromous fish habitat should consider the entire fluvial system. Managers should use natural stream processes to regulate channel conditions rather than strive for absolute control by artificial means.

67. **Kelsey, H.M.** 1980. A Sediment Budget and an Analysis of Geomorphic Processes in the Van Duzen River Basin, North Coastal California 1941-75. Geol. Soc. of Am. Bull. 91 (Part 11): 1119-1216.

Of the many factors which influence the sediment budget of the basin and the manner of sediment routing through the basin, it is evident that the role of major storms is crucial in initiating or accelerating large landslides, generating tremendous quantities of runoff, causing widespread gully widening and headward cutting, and mobilizing large amounts of bedload for short time spans. More frequent but less severe climatic events are important sediment transporters, but a significant amount of sediment they move (especially bedload) is delivered to the stream network by the infrequent larger events. Much of the stream landsliding and bank erosion during the smaller, more frequent storms are indirectly caused by channel and slope changes initiated by the high magnitude, infrequent storm event. Therefore, large magnitude and infrequent storms, have a significantly greater effect on total sediment discharge and on landscape formation and a much longer lasting effect on channel morphology in this region of high sediment yield than similar types of floods have on less mountainous terrain underlain by more stable geologic units.

The current sediment yield from the basin, 2570 $t/km^2/yr$, is from three to six times the maximum possible long-term rate since the late Miocene, based on a landform reconstruction of the basin. The current, rate, which is probably one of the highest ever,. may in part reflect recent uplift, but landuse of the past century has been a major contributing factor.

68. **Klein, R., R. Sonnevil and D. Short.** 1987. Effects of Woody Debris Removal on Sediment Storage in a Northwest California Stream. p. 403-405. In R.L. Beschta et al. (eds.): Proceedings: Symposium on Erosion and Sedimentation in the Pacific Rim. International Assoc. of Hydrol. Sci. August, 1987, Corvallis, Oregon. IAHS Publication 165, Wallingford, Oxfordshire, U.K.

Removal of large debris resulted in a loss of channel structures which stored smaller woody debris and sediment. Following debris removal, the physical effects of floods have been to decrease the volumes and centralize the locations of woody debris and stored sediment.

Channel processes documented by this study parallel those observed by Beschta (1979) and Bilby (1984).Removal of woody debris from streams draining forested steeplands may have significant and long lasting effects on channel morphology and subsequent biological productivity, emphasizing the need to approach management of woody debris with caution. Because inputs of new woody debris through blowdown and landsliding are infrequent, especially if streamside supply is reduced by logging, channel systems are slow to recover from complete debris removal. A more conservative approach of partial barrier removal warrants consideration, as the loss of adequate supply and even distribution of large woody debris in a channel system may require decades or centuries to be regained through natural processes.

69. **Kochel, R.C.** 1987. Geomorphic Impact of Large Floods: Review and New Perspectives on Magnitude and Frequency. In V.R. Baker, R.C. Kochel, and P.C. Patton (eds.). Flood Geomorphology. John Wiley and Sons.

70. **__________, D.F. Ritter, and J. Miller.** 1987. Role of Tree Dams in the Construction of Pseudo-Terraces and Variable Geomorphic Response to Floods in Little River Valley, Virginia. Geology 15: 718-721.

Geomorphic response to a 1985 flood in Little River Valley, northern Virginia, was different in magnitude and style from the largest historic flood in the same valley in 1949. The primary geomorphic activity during the 1985 flood was severe bank erosion and channel-gravel deposition rather than the debris flow and avalanching of the 1949 event. An unusual and widespread phenomenon of the recent flood was that large trees eroded and transported by the floodwater were aligned parallel to the river banks and, at isolated sites, were braced and stacked against trees still standing on the floodplain. Lateral barriers or dams created from these displaced trees allowed the channel to be locally aggraded above the level of the floodplain. In these reaches, little, if any, river gravel was deposited on the floodplain, even though the adjacent channel floor was raised well above that surface. The river has now shifted around the filled segments, leaving flat, isolated surfaces, underlain by channel gravel, standing above the level of the modern floodplain. These features may be mistaken for terraces after they become vegetated and the trees bracing the gravels decay. Interpreting these surfaces to be terrace remnants would lead to a faulty reconstruction of geomorphic history in the Little River valley and other valleys where floodplain morphology is controlled by infrequent flood events.

71. **Lammel, R.F.**, 1972. Natural Debris and Logging Residue Within the Stream Environment. M.Sc. Thesis. School of Forest Engineering, Oregon State University, Corvallis, Oregon.

Amounts of natural debris in small headwater streams under old-growth stands of Douglas-fir vary from 6 1/2 tons per 100 ft. of stream to 26 tons per 100 ft. of stream, depending on terrain and timber characteristics and sequence in the natural accumulation-flushing cycle. Approximately 10% of the weight of total debris is in the size-class smaller than 10 cm in diameter.

After falling, there was an increase of debris depending on stream protection measures, falling methods and environmental factors.

After yarding, the amount of total debris was reduced on the average to almost 50% from what it was originally. At the same time, the amount of branch-type debris increased although the amount of finer debris (<1 cm) decreased.

A wide buffer-strip provided an almost complete physical barrier against debris movements, while a very small buffer-strip provided much less stream protection in terms of logging residue. Cable-assist falling methods minimize breakage and provided for cleaner yarding as compared to conventional timber falling.

72. **Lestelle, L.C.** 1978. The Effect of Forest Debris Removal on a Population of Resident Cutthroat Trout in a Small Headwater Stream. M.Sc. Thesis, University of Washington, Seattle. 86p.

73. **Lestelle, L.C. and C.J. Cederholm.** 1984. Short-Term Effects of Organic Debris Removal on Resident Cutthroat Trout. p. 131-140. In W.R. Meehan, T.R. Merrel, and T.A. Hanley (eds.): Proceedings: Symposium on Fish and Wildlife Relationships in Old-growth Forests. Am. Inst. of Fish. Res. Biol. Morehead City, North Carolina.

Excessive cleanup of logging residues along small streams can deplete the stream environment of large, stabilized organic debris. An experiment was conducted to determine the effects on a resident salmonid population of overcleaning a stream course of organic debris. The study was conducted in two headwater streams of the Clearwater River in Washington during 1972 and 1973. Clearing of the stream had little or no effect on numbers and biomass of cutthroat (Salmo clarki clarki) immediately after alteration and prior to winter. Subsequently, population reductions occurred in the treated stream over winter 1972-1973, but these losses were short-term. The decline in number of overwintering trout was apparently associated with habitat instability brought on by the removal of large organic debris from the stream channel. Within 1 year of debris removal, the cutthroat trout population had returned to pretreatment levels. Also, the physical habitat characteristics of the altered stream were largely restored to pretreatment conditions within 1 year of debris removal. If there had not been a source of debris to replace that which was removed, habitat and fish recovery may have been slower.

74. **Lienkaemper, G.W. and F.J. Swanson.** 1987. Dynamics of Large Woody Debris in Old Growth Douglas-Fir Forests. Can. J. For. Res. 17: 150-156.

Transfer of large woody debris (>10cm diameter) from old-growth Douglas-fir (Pseudotsuga menziesii (Mirbel) Franco) forests into five first- to fifth-order stream reaches (drainage areas of 0.1 to 60.5 km^2) has ranged from 2.0 to 8.8 $Mg.ha^{-1}.year^{-1}$ in 7-to 9-year study periods. Amounts of large woody debris in these range from 230 to 750 $Mg.ha^{-1}$, with generally lower values in larger channels. The addition of woody debris is widely scattered in time and space and comes mainly from single trees rooted away from the stream bank. We infer that wind is a major agent for entry of wood into these streams. Downstream movement of debris is strongly related to length of individual pieces; most pieces that moved were shorter than bankfull width.

75. **Likens, G.E. and R.E. Bilby.** 1982. Development, Maintenance and Role of Organic-Debris Dams in New England Streams. p. 122-245. *In* F.J. Swanson et al. (eds.): Sediment Budgets and Routing in Forested Drainage Basins. USDA Forest Service, Gen. Tech. Rep. PNW-141. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

We propose that the formation of organic-debris dams on streams depends primarily on the size of tree (log) available. After disturbance, organic-debris dams are at first diminished and then form on larger and larger stream channels as the terrestrial ecosystem develops, and as a result, the regulation of erosion and transport of dissolved and particulate material from the landscape is enhanced. The species composition and phase of development of hardwood forests also may affect the occurrence and longevity of organic-debris dams. Steady-state amounts of organic matter in stream channels may reflect the stream order, as well as the developmental phase of the terrestrial ecosystem.

76. **Lisle, T.E.** 1982. Effects of Aggradation and Degradation on Riffle-Pool Morphology in Natural Gravel Channels, Northwestern California. Water Resour. Res. 18: 1643-1651.

After the flood of December 1964, 12 gauging sections in northern California widened as much as 100% and aggraded as much as 4 m, and then degraded to stable levels during a period of 5 years or more. As channels aggraded, bed material became finer, and low to moderate flow through gauging sections in pools became shallower, faster, and steeper. Comparisons of longitudinal profiles also show the diminishment of pools as well as a decrease in bar relief accompanying the excessive sediment load. As gauging sections degraded, hydraulic geometries recovered to a limited degree; full recovery probably depends on channel narrowing and further depletion of sediment supply. The hydraulic changes with aggradation indicate an increase in the effectiveness of moderate discharges (less than 1- to 2-year recurrence interval, annual flood series) to transport bed load and shape the bed. Bars become smaller, pools preferentially fill, and riffles armoured with relatively small gravel tend to erode headward during falling stages and form a gentler gradient. Excess sediment can thus be more readily transported out of channels when additional contributions from watersheds are usually slight.

77. __________ 1986a. Stabilization of a Gravel Channel by Large Streamside Obstructions and Bedrock Bends, Jacoby Creek, Northwestern California. Geol. Soc. Am. Bull. 97: 999-1011.

Jacoby Creek (bed width = 12 m; bankfull discharge = 32.6 m^3/s) contains stationary gravel bars that have forms and positions controlled by numerous large streamside obstructions (bedrock outcrops, large woody debris, and rooted bank projections) and bedrock bends. Bank-projection width and bar volume measured in 104 channel segments 1 bed-width long are significantly cross-correlated at lags of -1, 3, and 4, indicating the tendency for large obstructions and bends to form bars 3 to 4 bed-widths downstream and 1 bed-width upstream. All of the 18 bars downstream of large obstructions or bends in the study reach were along the obstruction side of the channel or outside bank of the bend. Most of the pools (85%) were next to large obstructions or in bends; conversely, 92% of large obstructions or bends had pools. Comparison of the volume of four bars with volumetric bar changes and volume of bedload transported during four high-flow events suggests that rates of sediment transport were sufficient to cause major changes in bars during bankfull events. The only important channel changes observed in 4 yr, however, have been associated with the movement of large woody debris and with changes in the angle at which the flow approaches an obstruction.

A general model is proposed that large obstructions and non-alluvial bends stabilize the form and location of gravel bars. Bars are stabilized by two related mechanisms.

1. Large obstructions and bends cause intense, quasi-steady, secondary circulation in scour holes that terminate upstream bars at fixed locations. Obstruction width, channel deflection, scour-hole width, and bed width were measured at 26 obstructions. These data show that obstructions wider than approximately one-third of the bed form "pools" spanning the entire channel and, thus, terminating bars; smaller obstructions form "scour holes" contained within a single bar.

2. Bars are deposited upstream of large obstructions and sharp bends because of backwater reductions in stream power. Bars are deposited downstream because flow energy is expended around obstructions and

bends and because the flow expands downstream of constrictions that result from large obstructions.

The formation of bars and pools inherent in many gravel channels can, thus, be enhanced and fixed in position by flow structures set up around large obstructions and bends formed of resistant materials.

78. ________ 1986b. Effects of Woody Debris on Anadromous Salmonid Habitat, Prince of Wales Island, Southeast Alaska. North Am. J. of Fish. Man. 6: 538-550.

The effects of woody debris on anadromous salmonid habitat in eight streams on Prince of Wales Island, southeast Alaska, were investigated by comparing low-gradient (2-9%) first- or second-order streams flowing through either spruce-hemlock forests or 6-10-year-old clearcuts, and by observing changes after debris was selectively removed from clear-cut reaches. Woody debris decreased the rate of shallowing as discharge decreased, thus helping to preserve living space for fish during critical low-flow periods. Debris dams were more frequent in clear-cut streams (14.9/100 m), which contained more debris, than in forested streams (4.2/100 m). As a result, total residual pool length (length when pools are filled with water but there is no flow) and length of channel with residual depth greater than 14 cm-the depth range occupied by 84% of coho salmon (Oncorhynchus kisutch) were greater in clear-cut streams than in forested streams. Greater volumes of woody debris in clear-cut streams produced greater storage of fine sediment (<4-mm diameter) unless the stream gradient was sufficiently high to flush sediment from storage. One-half of the debris dams broke up or were newly formed over a 3-year period, which suggests that they usually released sediment and woody debris before the pools they formed were filled with sediment. Woody debris removal decreased debris-covered area, debris dam frequency, and hydraulic friction in some cases but, in others, these variables were unaffected or recovered within 2 years after erosion and adjustment of the streambed. No consistent differences in pool dimensions were found between treated and untreated clear-cut reaches. Comparisons of habitat in forested and clear-cut streams suggested that removing debris from clear-cut streams reduced salmonid carrying capacity. Retention and natural reformation of debris dams in cleared reaches prevented the expected deterioration of habitat. However, the removal and destabilization of existing woody debris may cause depletion of debris before riparian trees can regrow and furnish new material to the clear-cut streams.

79. **Long, B.A.** 1987. Recruitment and Abundance of Large Woody Debris in an Oregon Coastal Stream System. M.Sc. Thesis. Oregon State University, Corvallis, Oregon.

80. **Lyons, J.K. and R.L. Beschta.** 1983. Land Use, Floods and Channel Changes: Upper Middle Fork Willamette River, Oregon (1936-1980). Water Resour. Res. 19: 463-471.

Flow trends and channel characteristics from 1936 to 1980 were evaluated for the Middle Fork Willamette River, which drains a 668-km^2 forested watershed in the Cascade Mountains of western Oregon. An inventory of aerial photographs from 1959 to 1972 shows that landslides associated with roads and in clearcuts were 27 and 23 times more frequent, respectively, than in forested areas. Numerous landslides unloaded sediments directly into the drainage system; most landslides appear to have been initiated during a large flood (return period greater than or equal to 100 years) of December 22, 1964. Analysis of precipitation and peak flows (greater than 100 m^3 s-1) from 1958 to 1980 by means of power function models suggests a trend of increasing flows as timber harvesting and road building expanded in the basin. Changes in channel pattern, documented from aerial photographs, show major increases in channel width from 1959 to 1967 and a trend of decreasing width from 1967 to 1980. During summer low flows in 1979 and 1980, 65 cross sections of the channel were surveyed to provide detailed measurements of existing channel conditions. Channel widths of 62% of the aggraded reaches were significantly greater (x = 0.05) than those for nonaggraded reaches.

81. **MacDonald, A. and E.A. Keller.** 1987. Stream Channel Response to the Removal of Large Woody Debris, Larry Dam Creek, Northwestern California. p. 405-406. In R.L. Beschta et al. (eds.): Proceedings: Symposium on Erosion and Sedimentation in the Pacific Rim. Internat. Assoc. of Hydrol Sciences, August, 1987, Corvallis, Oregon. IAHS Publication 165. Wallingford, Oxfordshire, U.K.

Wherever large woody debris (LWD) is a significant component of channel roughness, its removal has the potential to alter all aspects of local channel morphology. The resulting channel form is then controlled by remaining randomly distributed large roughness elements (LRE's), as described by Lisle (1986); these remaining LRE's may be bends, exhumed or newly introduced woody debris, or bedrock outcrops. In Larry Damn Creek, the net result of removal of LWD accumulations has been a tendency for the channel pattern to evolve towards a more "alluvial" state, stabilized by bends at bedrock outcrops and woody debris-defended banks.

To examine the mechanisms by which LWD controls local energy expenditure, and consequent patterns of water depth, velocity,and sediment storage, 70 m^3 of LWD were removed from Larry Damn Creek, a third order (area = 3.9 km^2) tributary in the Redwood Creek water shed.

The most notable effects of debris removal were (1) the local increase (up to 250%) in water velocity through the vicinity of the debris jams at measured discharges as a result of displaced channel roughness and decreased sinuosity of the low flow thalweg, (2) 100 m^3 of sediment that was entrained solely from within the affected reach in the first year after debris removal, and (3) the creation or deepening of pools at bends above and below the two debris jams at the expense of numerous scour pools within the jams.

A sediment routing model based on measured scour and fill was used to describe the movement of fine-grained, debris-stored sediment (trapped behind the physical barriers of the jams and as backwater deposits upstream) into new storage sites. Bed material size is now coarser above and through the area of the removed debris jams and finer downstream, suggesting the sort of balance that must be evaluated when removing debris accumulations to improve fish habitat.

Channel morphology has stabilized around the following LRE's: major bends in the channel above and below the former location of the debris jams, sediment deposits associated with these bends, and a small amount of the original debris-stored sediment that was stabilized with vegetation prior to channel disturbance. At low flows, the net roughness of the reach surrounding the debris jams is therefore not significantly lower than it was prior to debris removal. This is due to the combined effects of higher grain roughness, a slight decrease in bed slope, and the two bends. Data from adjacent LWD-laden reaches suggest that this pattern probably persists at discharges up to bankfull as well.

82. **____________, E.A. Keller, and T. Tally.** 1982. The Role of Large Organic Debris on Stream Channels Draining Redwood Forests in North-Western California. p. 226-245. In D.K. Hardey, D.C. Marm, and A. MacDonald (eds.): Late Cenozoic History and Forest Geomorphology of Humbolt Co. California. Friends of the Pleistocene 1982 Pacific Cell Field Trip Guidebook.

83. **MacDonald, J.S. G. Miller, and R.A. Stewart.** 1988. The Effects of Logging, Other Forest Industries and Forest Management Practices on Fish: An Initial Bibliography. Can. Tech. Rep. of Fish. and Aquat. Sci. No. 1622. Fisheries and Oceans Canada, Fisheries Research Branch, Vancouver, British Columbia. 212p.

The bibliography provides a comprehensive list of approximately 1500 references that describe the direct effects of the forest industry on fish and fisheries. Despite its length, the bibliography does not deal fully with all aspects of forest ecology and fish habitat. Topics covered selectively include: water quality, stream channel morphology, streamflow, water supply, forest soils, forest fires, climate, toxicology and pollution. A list of other bibliographic sources is included. Indexes (subject, geographic and study sites) are provided.

84. **Marston, R.A.** 1978. Morphometric Indices of Stream Flow and Sediment Yield from Mountain Watersheds in Western Oregon. Siuslaw National Forest Rep. 00-04T0-9-226. USDA Forest Service, Corvallis, Oregon.

85. ____________ 1980. The Geomorphic Significance of Log Steps in Forest Streams of the Oregon Coast Range. Ph.D. Thesis. Oregon State University, Dept. of Geog., Corvallis, Oregon. 216p.

86. ____________ 1982. The Geomorphic Significance of Log Steps in Forest Streams. Ann. Assoc. Am. Geog. 72: 99-108.

A functional account of log steps in forest streams is provided by field surveys of 163 kilometres of streams in the central Oregon Coast Range. Natural treefall, rather than silvicultural activities, accounts for the majority of log steps. During low-flow conditions, dissipation of potential stream energy by log steps amounts to 6 percent, approximately equal to that by falls. There are no statistically significant differences regarding spatial distribution of log steps between study basins with contrasting silvicultural and natural stream inputs of large woody debris. However, significant spatial differences are revealed between streams of various orders, a finding that points to channel flushing capacity and stream-adjacent topography as dominant controls on log step development. Application of thermodynamic principles to stream systems demonstrates that neither falls nor log steps cause a statistically significant difference in equilibrium conditions os stream networks. The volume of sediment stored behind log steps in third-, fourth-, and fifth-order streams is 123 percent of the mean annual sediment discharge (suspended load and bed-load). Depriving some streams of log steps by stream clean-out or repeated harvest of stream-adjacent trees may initiate an episode of progressive erosion by not dissipating stream energy in excess of that needed to transport imposed sediment supplies. Addition of log steps to streams with energy already insufficient to balance sediment inputs and outputs may only serve to accentuate progressive deposition. Functions of instream large woody debris not incorporated as log steps must also be addressed in forest management decisions.

87. **Meehan, W.R. et al.**, 1969. Some Effects of Clearcutting on Salmon Habitat of Two Southeast Alaska Streams. USDA Forest Service, Res. Pap. PNW-82. Pacific Northwest Forest and Range Experiment Station, Juneau, Alaska. 45p.

The objective of the study was to determine the effects of clearcutting on the physical factors of salmon spawning streams. The report summarizes the research and describes the main conclusions regarding the effects of clearcutting on streamflow, suspended sediment, water temperature, and log debris.

Three watersheds in the vicinity of Hollis, Prince of Wales Island, were selected as the study area; about one-fourth of Maybeso Creek watershed (total area, 15.2 square miles) and one-fifth of the Harris River watershed (31,8 square miles) were clearcut by high-lead cable logging methods.

Stream flow from the two logged watersheds did not change in comparison with nearby, unlogged Indian Creek. Likely changes in streamflow as a result of logging might have been detected if precipitation and streamflow had been measured with an accuracy of .+ 2-3 percent. This accuracy was not approached.

Sampled concentrations of suspended sediment for given levels of Harris River were higher during logging than before, the changes were not statistically significant.

Maximum increase in average monthly stream temperatures at the sites was 4° F. However, maximum observed temperatures appear to have increased up to 9° F. in the summer months. The temperature increase is believed to be associated with the removal of stream side timber. Although changes in winter temperatures resulting from logging are not conclusive, the data suggests that logging has little effect on the 32° to 34° F. temperatures that extend to spring.

Debris increased in Maybeso Creek during and after logging. This is probably due to logging of relatively high-volume timber and to poisoning of alder on the stream banks. A small increase in absolute number of logs and debris pieces occurred in the Harris River during and after clearcutting. The initial number of pieces was small compared with Maybeso Creek and remained so during and after logging.

Increased amounts of logs and debris in the streams during and after clearcutting could reduce access to and amount of suitable spawning area; however, such barriers were not observed during the study.

88. **Megahan, W.F.** 1982. Channel Sediment Storage Behind Obstructions in Forested Drainage Basins Draining the Granitic Bedrock of the Idaho Batholith. p. 114-121. In F.J. Swanson et al. (eds.): Sediment Budgets and Routing in Forested Drainage Basins. USDA Forest Service, Gen. Tech. Rep. PNW-141. Pacific Northwest Forest and Range Experimental Station, Portland, Oregon.

Data on sediment storage behind obstructions were collected on seven forested, mountain drainage basins in the Idaho Batholith for a 6-year period from 1973-78. Four of the drainage basins were undisturbed throughout the study period, one contained an old road, and two were logged during the course of the study. The total volume of sediment stored behind obstructions varied between drainage basins and years in response to changes in bankfull channel width and annual peak-flow rates, respectively. Logs were the most important type of obstruction because they had the greatest longevity and stored the greatest amount of sediment. An average of 15 times more sediment was stored behind obstructions than was delivered to the mouths of the drainages as annual average sediment yield. Logging reduced total channel-sediment storage behind obstructions because many natural obstructions were destroyed by felling and subsequent component of the overall sediment routing through forested drainage basins. Accordingly, erosion and sedimentation monitoring must be carefully designed to avoid misinterpretation. Also, some guidelines are presented to help minimize the change in channel-sediment storage caused by timber harvest.

89. ___________ **and R.A. Nowlin.** 1976. Sediment Storage in Channels Draining Small Forested Watersheds in the Mountains of Central Idaho. p. 4.115-4.126. In Proceedings: Third Federal Inter-Agency Sedimentation Conference, Denver, Colorado.

The role of sediment storage was studies in channels draining seven small forested watersheds in central Idaho. Data collection included an inventory of sediment deposited behind channel obstructions, detailed surveys of channel cross sections, and measurements of annual sediment yields in sediment detention reservoirs.

Extremely large volumes of sediment were trapped behind channel obstructions in the 1973 and 1974 sample years; only about 10 percent of the sediment stored appeared as sediment yield. Most obstructions shifted from one year to the next; so the stability of the remaining sediment stored in the channels was questionable.

The series of detailed channel cross sections was used in evaluating annual changes in the total volume of sediment stored on channel bottoms. Considerable aggregation occurred during the low flow year (1972-173), whereas degradation occurred during the high flow year (1973-74). Annual watershed erosion was determined by entering the annual sediment yields and the annual change in stored sediment into a continuity equation.

90. **Mosely, M.P. 1981. The Influence of Organic Debris in Channel Morphology and Bedload Transport in New Zealand Forest Streams. Earth Surface Processes and Landforms 6: 571-579.**

The behaviour and form of, and bedload sediment transport through, a 3.5 m wide forest stream have been monitored for nearly three years. Bedload transport is highly episodic and spatially variable, and is controlled less by water discharge than by sediment availability. Organic debris in the channel creates temporary base levels and sites at which coarse sediment may remain stored for long periods; collapse or disruption of log and debris jams makes sediment available for transport in only a small proportion of the runoff events that are actually competent to move the material. Even then, sediment travels only a short distance before being redeposited, frequently behind debris accumulations further downstream. Rates of sediment transport during a given runoff event can vary markedly over short distances along the stream, again depending on whether sediment was made available for transport by log jam collapse upstream. Organic debris is therefore a major constraint on the application of physical laws and theories to explaining sediment movement in, and the morphology of, this stream.

91. **Murphy, M.L., et al.** 1985. Role of Large Organic Debris as Winter Habitat For Juvenile Salmonids in Alaska Streams. p. 251-262. In Proceedings: Western Association of Fish and Wildlife Agencies 1984.

The objectives of the study were (1) to assess effects of clear-cut logging on juvenile salmonids (Oncorhynchus kisutch, Salmo gairdneri, S. clarki, and Salvelinus malma) rearing in streams in southeastern Alaska, (2) evaluate the effectiveness of buffer strips in protecting fish habitat from any adverse effects of logging, and secondarily, (3) determine whether blowdown in buffer strips is harmful to juvenile salmonid habitat.

Large organic debris appears to be one of the most important habitat features for wintering salmonids (Oncorhynchus kisutch, Salmo gairdneri, S. clarki, and Salvelinus malma). Logging can have both positive and adverse effects on winter habitat, depending on whether debris is removed or added to streams. Clear-cutting without buffer strips reduces the amount of winter habitat when the streams are over-cleaned, timber is salvaged from them, and natural debris is destabilized. In addition, future sources of debris are removed when trees are cleared from both stream banks. Buffer strips protect natural debris in the stream and provide future debris for the stream. Research is needed to determine quantitative relationships between woody debris and success of spawning and rearing salmonids to determine how much debris is needed for any given stream. This information can then be used to design buffer strips that will supply a sufficient quantity of debris to the stream during subsequent harvest rotations.

92. __________**, et al.** 1986. Effects of Clear-cut Logging With and Without Buffer Strips on Juvenile Salmonids in Alaskan Streams. Can. J. Fish. Aquat. Sci. 43: 1521-1633.

To assess short-term effects of logging on juvenile Oncorhynchus kisutch, Salvelinus malma, Salmo gairdneri, and Salmo clarki in southeastern Alaska, we compared fish density and habitat in summer and winter in 18 streams in old-growth forest and in clearcuts with and without buffer strips. Buffered reaches did not consistently differ from old-growth reaches; clear-cut reaches had more periphyton, lower channel stability, and less canopy, pool volume, large woody debris, and undercut banks than old-growth reaches. In summer, if areas had underlying limestone, clear-cut reaches and buffered reaches with open canopy had more periphyton, benthos, and coho salmon fry (age 0) than old growth reaches. In winter, abundance of parr (age >0) depended upon the amount of debris. If debris was left in clear-cut reaches, or addressed in buffered reaches, coho parr were abundant (10-22/100 m^2). If debris had been removed from clear-cut reaches, parr were scarce (<2/100 m^2). Thus, clear-cutting may increase fry abundance in summer in some streams by increasing primary production, but may reduce abundance of parr in winter if debris is removed. Use of buffer strips maintains or increases debris, protects habitat, allows increased primary production, and can increase abundance of fry and parr.

93. **Nechako Fisheries Conservation Program Steering Committee.** 1990. In-Stream Habitat Modifications. p. 11. In Nechako Fisheries Conservation Program Annual Report 1989/90. Nechako Fisheries Conservation Program: A Joint Program of the Government of Canada, Alcan and the Province of British Columbia.

In 1989, new habitat structures were built which include debris traps, point bars and back eddies. These were assessed for structural integrity after the summer high flow period. In addition, structures built in 1988, such as brush piles, rootwad sweepers and debris catchers, were assessed for their ability to withstand winter ice conditions and summer cooling flow releases.

94. **Robison, E.G.** 1988. Large Woody Debris and Channel Morphology on Undisturbed Streams in Southeast Alaska. M.Sc. Thesis. Oregon State University, Corvallis, Oregon. 136p.

95. **__________ and R.L. Beschta.** 1990. Coarse Woody Debris in Undisturbed Coastal Streams in Southeast Alaska, U.S.A. Earth Surface Processes And Landforms 15: 149-156.

Coarse woody debris and channel morphology were evaluated for five low-gradient streams that ranged from first to fourth order (0.7 to 55 km^2 watershed area). Debris volumes were directly related to variations in bankfull width. Woody debris was associated with 65 to 75 per cent of all pools and the relative proportion of types of pools (ie. plunge, lateral scour, ect.) varied with stream size. High variability in channel depths and widths was common. The results provide benchmark values of woody debris loadings and channel morphology for undisturbed coastal Alaskan stream systems.

96. **Russell L.R.** 1975. An Annotated Bibliography on Steelhead Trout and General Salmonid Ecology. Fish. Tech. Circ. No. 14. British Columbia Ministry of Environment, Fish and Wildlife Branch, Victoria, B.C.

This bibliography contains 323 annotated references on steelhead trout ecology and 248 additional references which have been annotated. Also included are 116 annotated references on general salmonid ecology along with 157 additional, non-annotated references.

97. **Sedell, J.R., et al.** 1988. What We Know About Large Trees That Fall Into Streams and Rivers. p. 47-49. In C.Maser et al. (eds.): From the Forest to the Sea: A Story of Fallen Trees. USDA Forest Service, Gen. Tech. Rep. PNW-GTR-229, Pacific Northwest Research Station, Portland, Oregon.

The dynamics of coarse woody debris (any dead standing or fallen tree stem on land or in water at least 4 inches in diameter at breast height on snags and at the large end on fallen trees) in forests and plantations of coastal Oregon are summarized in this chapter on streams and rivers.

The most productive habitats for salmonid fish are small streams associated with mature and old-growth coniferous forests where large organic debris and fallen trees greatly influence the physical and biological characteristics of such streams.

98. **__________, and J.L. Froggatt.** 1984. Importance of Streamside Forests to Large Rivers: The Isolation of the Willamette River, Oregon, U.S.A., From its Floodplain by Snagging and Streamside Forest Removal. Verhandlungen-Internationale Vereinigung fuer Theorelifche und Angewandte Limnologie (International Association of Theoretical and Applied Limnology) 22: 1828-1834.

The pristine riparian forest extended 1.5-3 km on either side of the river. The pristine river was a series of multiple channels, sloughs, and backwater areas. Historically, the floodplain and valley had extensive marshes. Numerous downed trees helped to create and maintain shoals, multiple channels, oxbow lakes, and complex aquatic habitats at the outside bends in the river. After 80 years of snag removal and riparian forest destruction, there now exists one main channel, few downed trees, relatively simple and homogeneous habitat for aquatic vertebrates, and a four-fold decrease in river shoreline.

The few floodplain areas with extensive riparian forests along our major rivers must be treated as the last reserves of species and habitats approximating the condition of pristine rivers. These relics of the past will hold the key to relating inferences from the historical record to quantitative differences between what we now perceive as the normal conditions and how the river interacted with the terrestrial ecosystem and its massive quantities of wood inputs in the past.

99. **__________ and K.J. Luchessa.** 1981. Using Historical Record as an Aid to Salmon Enhancement. p.210-223. In Proceedings: Symposium on Acquisition of Aquatic Habitat Inventory Information. Portland, Oregon.

Historically, wild anadromous fish stocks evolved with stream systems that were obstructed by fallen trees, beaver dams, and vegetation growing in and beside the channels. River systems as large as 7th order had large numbers of fallen trees in their channels and often were obstructed by drift jams that were up to 1500 m long. The main river channels contained abundant gravels and fine sediments. Habitat complexity was great because of scour around boulders and fallen trees, and the presence of numerous and extensive stable side channels and sloughs. These pristine streams interacted intensively with their flood plains. Historical records document over 100 years of "diligent" stream and river cleanup. Primary activities included removal of boulders, large woody debris, and other obstructions from channels. We believe that historical documentation of the ways unmanaged streams interacted with the streamside forest allows us to know how far we have deviated from the optimum habitat requirements for various salmonids. Until we understand the structure of undisturbed habitats that wild stocks develop within, and the sequence of changes that have occurred in those habitats, our present protection and enhancement efforts will lack both a rational context and effective direction.

100. ___________**, F.J. Swanson, and S.V. Gregory.** 1984. Evaluating Fish Response to Woody Debris. p.222-245. In T.J. Hassler (ed.): Proceedings: Pacific Northwest Stream Habitat Management Workshop. Am. Fish. Soc. West. Div. Humbolt State University, Arcata, California.

Fish respond favourably to debris in streams. Pristine streams contain vast amounts of large wood in their channels and along their edges. For decades the principal tool for fish habitat management has been debris removal. We examine the evidence for evaluating the role coarse woody debris plays in the geomorphology of streams, specifically: longitudinal profiles, channel patterns and position, channel geometry, sediment and organic matter storage, and channel dynamics. From this physical template we examine the fisheries implications of coarse woody debris (CWD): blockage to migration, water quality, and summer and winter rearing habitat. The issue of current management practices for providing wood inputs to stream is discussed in terms of the question how much wood is enough.

101. ___________ **and F.J. Triska.** 1977. Biological Consequences of Large Organic Debris in Northwest Streams. p. 1-10. In Logging Debris in Streams Workshop ll. Oregon State University, Corvallis, Oregon.

This paper will focus on the biology and of both large and fine debris from an overall perspective. We will emphasize the nature of the input of energy into small streams, the role of aquatic insects and microbes in the breakdown of woody material, and the different stream habitats which organic debris provides. The objective will be to biologically define a forest stream. This definition of the natural stream constitutes an important prerequisite to "rehabilitating" or "improving" streams.

The key to retention of fine organic debris in these streams is the presence of great volumes of large organic debris. In small streams during the winter rainy months debris dams sieve out fine debris. During the summer low flow months these large debris dams simulate a trickle filter in a sewage plant by retaining very fine organics and soaking up and immobilizing dissolved nutrients with the aid of the microbes.

The great diversity of these small stream habitats as to substrate and current patterns allow many different kinds of communities to develop. Removal of these debris dams helps channelize the stream and increases current velocity. The sediments associated with the debris dams often accumulate in unsteady berms on the stream bed which quickly erode once the rate of flow changes. Organisms which have used the substrate as a habitat are destroyed once the berms start to move. Occasionally more or less consolidated berms develop within the stream channel which may produce a favourable habitat for aquatic life. In some areas organic debris removal homogenizes the bed, thus reducing its roughness and diversity which in turn destroys the diversity of other current patterns. This inevitably leads to reduction of aquatic life in channelized or debris cleaned areas.

102. **Sheridan, W.L.** 1969. Effects of Log Debris Jams on Salmon Spawning Riffles in Saginaw Creek. USDA, Forest Service, Alaska Region, Feb. 1969, 12p.

A preliminary study of the effects of logging debris jams on salmon spawning habitat was made in Saginaw Creek on Kuiu Island in June 1968. This study showed that about 27 percent of the area in one lineal mile of this stream had been eliminated as spawning area by log jams. Recommendations are made for judicial removal of jams and leaning trees, especially while a logging operator is in the watershed. Discounted benefit cost ratio is 34:1 for removal of a log jam and 342:1 for removal of leaning trees.

103. **Shields, D.F.** 1983. Design of Habitat Structures For Open Channels. Jour. Water Res. Plan. and Man. 109(4): 331-344.

In many cases, channel modifications have extremely adverse impacts on aquatic communities. Rudimentary design guidelines are presented for simple structures (sills, current deflectors, and individual boulders) used to accelerate biological recovery of modified stream channels. These structures increase the physical habitat diversity of a modified channel. Data from nine case studies are presented in tabular form, including stream channel characteristics, structure dimensions, and an analysis of biological effectiveness and structural durability. Available literature on habitat structures focuses on applications to unenlarged coldwater streams with coarse bed material. Documented experience with enlarged warmwater streams that have poorly armoured channels is extremely limited.

104. ____________ **and N.R. Nunnally.** 1984. Environmental Aspects of Clearing and Snagging. Jour. of Environmental Eng. 110(1): 152-165.

Clearing and snagging is used as an economical technique for reducing the frequency and duration of high frequency flooding in environmentally sensitive locations. Riparian vegetation and the organic debris it produces influence stream morphology, water quality, and aquatic and terrestrial ecosystems. Complete clearing and snagging has detrimental effects on these stream characteristics. Modified clearing and snagging is less damaging to the environment. Major modifications involve: (1) Selective removal and disposal of trees and snags based on size, location, condition, and habitat value; (2) labour intensive construction techniques; (3) access controls; and (4) work scheduling to avoid fish spawning or other environmentally sensitive periods. Guidelines for modified clearing and snagging are discussed, and analytical approaches to estimating effects of vegetation and snags on flow resistance are reviewed.

105. **Shirvell, C.S.** 1990. Role of Instream Rootwads as Juvenile Coho Salmon (Oncorhynchus Kisutch) and Steelhead Trout (O. mykiss) Cover Habitat Under Varying Streamflows. Can. Jour. Fish. Aquat. Sci. 47: 852-861.

Coho salmon fry (Oncorhynchus kisuch) and steelhead parr (O. mykiss) occupied previously infrequently-used mid-channel areas of Kloiya Creek, British Columbia, Canada, once artificial rootwads were placed there. Ninety nine percent of all coho salmon fry and 83% of steelhead parr occupied positions downstream of natural or artificial rootwads during artificially created drought, normal, and flood streamflows. Fish associated with rootwads regardless of distance from shore, but steelhead parr preferred rootwads away from shore while coho salmon fry preferred rootwads next to shore. Coho salmon fry increased their use of natural rootwads where light remained low during droughts. Young fish apparently selected areas having slower water 80% of the time because they provided shelter from adverse current, and areas having reduced light intensities 20% of the time because they provided protection from predators. Juvenile coho salmon and steelhead in Kloiya Creek selected locations with slower water velocities and reduced light intensities irrespective of the physical structure that caused them.

106. **Smith, D.G.** 1976. Effects of Vegetation on Lateral Migration of a Glacier Meltwater River. Geol. Soc. Am. Bull. 87: 857-860.

A series of experiments were performed on bank materials of anastomosed channels in flood-plain silt deposits in the Alexandra Valley in Banff Park, Alberta, to determine the effect of vegetation roots on bank erodibility and lateral migration of channels. Underground roots from the dense growth of meadow grass and scrub willow provide the reinforcement of bank sediment and a riprap-like protection of channel banks from river erosion. Results from the experiments suggest that in cool environments with aggrading river conditions where overbank deposition of silt, clay, and fine sane dominate the valley fill, vegetation roots are able to rapidly accumulate and decay very slowly, thus affording protection to banks from erosion in deeper parts of the channels.

Experiments were performed with a specially designed erosion box, used as a means to simulate natural erosion conditions and measure the influence of vegetation roots in reducing bank erosion. Results indicate that the bank sediment with 16 to 18 percent by volume of roots with a 5-cm root-mat for bank protection, typical of the area, had 20,000 times more resistance to erosion than comparable bank sediment without vegetation. Assuming five severe erosion days per year, potential lateral channel migration would amount to 4.2 cm per year. Such resistance, due to vegetation, accounts for the remarkable stability of channels during the last 2,500 yr in the Alexandra Valley.

107. **Speaker, R., K. Moore, and S. Gregory.** 1984. Analysis of the Process of Organic Matter in Stream Ecosystems. Verhandlungen - Internationale Vereinigung fuer Theorelifche und Angewandte Limnologie (International Association of Theoretical and Applied Limnology) 22: 1835-1841.

Lotic ecosystems are substantially different than most other ecosystems because the continuous unidirectional flow through the system tends to transport matter to downstream reaches. This gives rise to the common erroneous view of streams as conduits or pipes. The process of retention removes matter from transport and makes it available for utilization by stream biota, thus providing a critical link between input and storage.

The retentive properties of a stream are functions of both hydrologic and substrate-related features. Heterogeneity of channel structure and current velocity creates obstructions and slack water areas that enhance retention efficiencies of streams. The retention of a particle in transport is a function of the probability of entrainment of the particle on an obstacle and the frequency of obstacles in the channel (Young et al. 1978). A particle will also be retained in areas where the current velocity is less than the velocity required to keep the particle in suspension. When one of these conditions is met, the particle will be retained until flow conditions change and it is transported downstream.

The influence of riparian vegetation on biological processes in streams extends beyond food resources and habitat. The effects of riparian vegetation on channel structure and organic inputs in streams determine the efficiency with which matter is retained. In this paper, we describe a method for the quantitative assessment of retention of particulate organic matter in streams and identify several major stream retention features that can be influenced by the structure and composition of riparian zones.

108. **Stack, W.R.** 1989. Factors Influencing Pool Morphology in Oregon Coastal Streams. M.Sc. Thesis. Oregon State University, Corvallis, Oregon. 115p.

Pool morphology was surveyed in 19 stream sections within the central Oregon Coast Range. Pool locations, sizes, spacings, numbers, and factors affecting pool formation were determined for each stream section. All sections were underlain by sedimentary rocks, had drainage areas ranging from 1.3 to 17.3 km^2, and had average water surface slopes from 0.5 to

5.6%. Stream sections were divided into two categories: (1) low timber harvest (<20% of watershed area harvested) and (2) higher timber harvest (>45% of watershed area harvested).

A "Rapid Bed Profile" (RBP) technique was developed to measure residual pool characteristics in each stream section. The RBP technique is a survey method that requires only thalweg depths and the average reach gradient. The technique was effective for classifying pools since it is objective, independent of flow, accurate, and time-efficient.

Residual pool size characteristics (e.g., volume) for the low timber harvest stream sections were positively correlated to a power function of drainage area. Stream sections with beaver dams, specially those with at least 10% of their reach length in beaver-caused pools, typically had larger residual pools. Pool size characteristics for high timber harvest stream sections.

The average spacing between residual pools was positively correlated to a power function of drainage area for low timber harvest stream sections (a negative correlation was found between the number of pools and drainage area). High timber harvest stream sections may be associated with an increased spacing and a decreased number of pools for larger watersheds (i.e., greater than 8 Km^2). However, the potential effects of previous large storms, changes in timber management practices, and/or the small number of streams surveyed preclude a definitive conclusion.

The frequency of occurrence of pool forming processes (e.g., plunge, deflection) was correlated with average water surface slope for the low timber harvest stream sections The percentage of plunge and impoundment processes increased as water surface slope increased while the percentage of deflection and under flow processes decreased. Two high timber harvest streams had a higher percentage of plunge pools than expected based on the relationships established for low timber harvest streams.

The frequency of occurrence of wood and boulder pool forming elements was correlated with an index of stream power (drainage area times average water slope) for the low timber harvest stream sections. As stream power index increased, the relative frequency of wood- formed pools increased. Wood and boulder combined, generally, made up 80% of the pool forming elements. The frequency of occurrence of pool forming elements was not different between low and high timber harvest stream sections.

109. **Stern, D.H. and M.S. Stern.** 1980a. Effects of Bank Stabilization on the Physical and Chemical Characteristics of Streams and Small Rivers: A Synthesis. USDI, Fish and Wildlife Service, Biological Service Program, FWS/OBS-80/11. 43p.

This report was prepared in response to numerous requests from field personnel for information on the impact of bank stabilization on streams and small rivers. Information is organized to show changes that occur in depth, velocity, temperature and other stream parameters. Strategies for dealing with some bank stabilization problems are also discussed briefly.

110. **Stern, D.H. and M.S. Stern.** 1980b. Effects of Stream Bank Stabilization on the Physical and Chemical Characteristics Of Streams And Small Rivers: An Annotated Bibliography. USDI, Fish and Wildlife Service, Biological Services Program, FWS/OBS-80/12. 78p.

This annotated bibliography provides a reference source of information on the impacts of bank stabilization on the physical and chemical characteristics of streams and small rivers. The bibliography has 213 references, and is indexed by 26 key subject headings. Papers range from technical documents to general discussions addressing the physical and chemical changes that result from various types of bank stabilization activities. Many of the annotations provide a thorough summary of pertinent information contained in the respective references.

111. **Sullivan, K. et al.** 1987. Stream Channels: The Link Between Forestry and Fisheries. p. 39-97. In T. Cundy and E.O. Salo (eds.): Proceedings: Symposium on Streamside Management-Forestry Fisheries Interactions, 1986, February 12-14. Institute of Forest Resources, University of Washington, Seattle.

The hydraulic characteristics of flow through channels are an important component of fish habitat. Salmonids have evolved in stream systems in which water velocity and flow depth vary spatially within the watershed and temporally on a daily, seasonal, and annual basis. Flow requirements vary during different phases of the freshwater life cycle of salmonids: free passage is necessary during migration of adults; clean and stable gravel beds ensure successful incubation of eggs; and adequate velocity and depth of flow conditions by timing the phases of the life cycle to take advantage of the seasonal discharge characteristics. Spatial variability enhances species diversity by creating a variety of habitats within stream reaches; these are partitioned among individual species and age groups having different tolerances for velocity, depth, and cover conditions.

Channel morphology is determined largely by sediment and water input to the channels, and is formed during storm events when flow is great enough to transport the coarse sediments lining the channel bed. The resulting channel shape consists of a sequence of recognizable units known as riffles, pools, and boulder cascades. Water flowing down the stream is forced continually to adjust its velocity and depth in response to the changing channel shape: flow is shallow and fast in riffles and slow and deep in pools. Large obstructions such as woody debris, boulders, and bedrock outcrops alter channel width, increasing the variation in velocity and depth in the vicinity of the obstruction and anchoring the position of pools. Discharge also varies through time, creating additional variations of hydraulic conditions.

Forest management can effect channel morphology by changing the amount of sediment or water contributed to the streams, thus disrupting the balance of sediment input and removal. Excessive input of coarse sediments from landslides can smooth the channel gradient by filling pools. Removing large woody debris from channels reduces sediment storage and eliminates the local hydraulic variability associated with the obstruction. Loss of habitat diversity by either mechanism may reduce or change the fish species found in a stream reach. If the changes result in decreased space, populations may also decrease. Strategies to minimize the effects of land management on channel morphology and fish habitat should include practices that minimize increases in coarse sediment input, and that preserve the morphologic complexity of the channel.

112. **Swanson, F.J. et al.** 1984. Organic Debris in Small Streams, Prince of Wales Island, Southeast Alaska. USDA Forest Service, Gen. Tech. Rep. PNW-166. Pacific Northwest Forest and Range Experimental Station, Portland Oregon.

Quantities of coarse and fine organic debris in streams flowing through areas clearcut before 1975 are 3 and 6 times greater than quantities in streams sampled in old-growth stands in Tongass National Forest, central Prince of Wales Island, southeast Alaska. The concentration of debris in streams of clearcut Sitka spruce-western hemlock forests in southeast Alaska, however, is about half that in streams of clearcut Douglas-fir-western hemlock forests in western Oregon. Management guidelines for maintaining natural debris conditions include minimizing the addition of fresh material to a channel during management activities, leaving natural accumulations of debris, and managing streamside areas for production of a continuous, long-term supply of large debris for channels. Considerations in planning stream cleanup include the length of time the debris has resided in the channel and the stability of debris, which is a function of its size, orientation, and degree of burial and decay.

113. ____________, **and G.W. Lienkaemper.** 1975. History and Physical Effects of Large Organic Debris in Western Oregon Streams. In Logging Debris in Streams, September, 9-10, Notes For a Workshop. Extension Service and Dept of Forest Engineering, Oregon State University, Corvallis, Oregon. 18p.

Large organic debris has historically been an important element in small mountain streams of the Pacific Northwest. The debris serves to slow the movement of inorganic and fine organic matter through the channel; it may be stabilized and remain in the channel for 10's to more than 100 years and it tends to stabilize some sections of a stream bed and banks while destabilizing other areas. The combination of clearcutting and complete removal of large debris in the channel may deprive a stream of this natural component of the system for a century or more. The consequences are likely to be downcutting and the effect "channelization" of the stream, accelerated transport of fine organic and inorganic sediment, and a possible decrease in overall biological productivity of the stream ecosystem. Therefore, stream debris management during logging operations should include leaving undisturbed the natural, stable organic debris in the channel.

The principal factors controlling the concentration, stability and functions of stream debris are the history and condition of the surrounding timber stand, flushing history of the channel, stability and abundance of bedload material, steepness of the channel and adjacent hillslopes, and slope stability in the drainage. Because of this complexity, each stream presents a unique situation which should be inspected in the field and considered on an individual basis before a debris management decision is made.

114. ____________, **and G.W. Lienkaemper.** 1978. Physical Consequences of Large Organic Debris in Pacific Northwest Streams. USDA Forest Service, Gen. Tech. Rep. PNW-69. Pacific Northwest Forest and Range Experimental Station, Portland, Oregon. 15p.

Large organic debris is a principal factor determining the biological and physical character of small and intermediate-sized streams in forested landscapes of the Pacific Northwest. Debris enters streams by blowdown, undercutting of streambeds, and mass movement processes on adjacent hillslopes. Debris is moved through channels by flotation at high water, in torrents and as dissolved and fine particulate matter following breakdown by wood processing organisms. Water and sediment routing in channels is controlled by large debris which may create a stepped profile. Stream energy is thereby dissipated at the relatively short, steep sections of channel so that much of the stream area may have a gradient less than the overall gradient of the valley bottom.

Debris in streams creates habitat for aquatic organisms both by serving directly as a substrate and by modifying streamflow to form depositional areas. Activity of consumer organisms tends to be concentrated in areas of wood and wood-created habitat. In undisturbed first-order streams, over 50 percent of total stream area may be comprised of wood and wood-created habitat; and in third-order streams, it may exceed 25 percent. Large pieces of debris reside in streams for decades and even longer than a century. This long residence time results in a continuing concentration of debris in streams during the 100+ years of stand recovery following wildfire, except when debris torrents flush channels.

A program to maximize future options for good stream management would involve: (1) leaving the natural debris in channels and introducing a minimum of additional debris; (2) leaving a buffer strip to help minimize alteration of the stream area and to serve as a source of large debris for the stream in the future; (3) minimize the debris avalanche potential, hence debris torrent potential, by improved unit and road layout, development, and maintenance.

115. ____________ **and G.W. Lienkaemper.** 1982. Interactions Among Fluvial Processes, Forest Vegetation, and Aquatic Ecosystems, South Fork Hoh River, Olympic National Park. p. 30-34. In E.E Starkey, J.F. Franklin, and J.W. Matthews (eds.): Ecological Research in National Parks of the Pacific Northwest. Forest Research Laboratory, Oregon State University, Corvallis, Oregon.

116. ____________**, G.W. Lienkaemper, and J.R. Sedell.** 1976. History, Physical Effects and Management Implications of Large Organic Debris in Western Oregon Streams. USDA Forest Service, Gen. Tech. Rep. PNW-56. Pacific Northwest Forest and Range Experimental Station, Portland, Oregon. 15p.

The theme of this paper is that streams and their biota develop through a long history of high concentrations of debris and that perhaps a closer look at the history of natural debris in stream environments will help in managing these streams in the future.

The quantity of debris in a stream channel at any time reflects a balance between the processes controlling the debris inputs and outputs of the stream system. The export of large organic debris is determined by the ability of the stream to float debris downstream, rates of decomposition and physical breakdown of debris in channels, and the probability of debris torrents flushing out the channel.

Observations indicate small streams draining moderately stable watersheds have contained abundant large organic debris for much of the past few thousand years.

The authors conclude that (1) large concentrations of debris in streams occur naturally; (2) debris may have residence times to more than a century; (3) debris increases the "roughness" of the channel, causing sediment and floated organic matter to be trapped and slowing the movement of these materials through the stream system; (4) a large portion of the stream drop is in fall over debris, thereby dissipating much of the stream's energy at a few points along the channel rather than more uniformally along the channel as in the case in similar streams which are debris-free; and (5) the impact of large debris on channel morphology is complex because debris causes widening and narrowing, deepening and shallowing, and stabilization and destabilization at different points along the channel bed and banks. On larger streams the which can float most of the debris which enters them the debris plays a rather minor role in the stream environment.

Effects of clearcutting and cleaning of stream corridors are: (1) removing large, pre-existing stable pieces of debris from the stream; (2) possibly increasing the concentration of small,unstable debris both by fresh input to the channel and by release of material previously stored behind large debris; and (3) eliminating the source of fresh, potentially stable pieces by removing the timber stand.

Likely long-term consequences of eliminating large organic matter from streams are that many small streams will undergo downcutting and become effectively "channelized" on bedrock or on a stable boulder pavement. A stream which had previously flowed over a series of steps formed by debris will assume a more uniformly steep profile and experience other changes in channel geometry. There will be a resulting decrease in diversity of stream habitat as biologically productive, debris related depositional pools are eliminated. Increased water velocity will also contribute to the accelerated transport of fine organic matter through the channel system, thereby decreasing the opportunity of stream organisms to process the material. Consequently, the removal of large debris from streams may reduce long-term biological productivity and increase the rate of sediment transfer from headwater streams to downstream areas.

Some generalized management guidelines are; (1) Minimize or eliminate any input of new material to the stream, (2) Base stream clearing decisions on biological considerations, (3) Leave pre-existing, stable pieces of large debris in the stream without disturbing them, and (4) When considering the trade-offs of buffer strips, recognize them as future sources of large stable debris for streams.

With both moderate and excessive debris loads in streams, there is no single, simple set of rules which can be applied indiscriminately. Each site presents a different set of conditions of stream biology, channel gradient, status of stream debris, conditions of surrounding timber stand, abundance and size of bedload, and slope stability in the drainage. The great complexity of the stream environment means each site must be inspected in the field and treated on an individual basis. Debris management problems call for a high degree of cooperation between specialists and administrative personnel.

117. **____________, J.B. Sedell, and G.W. Lienkaemper.** 1977. Studies of Organic Debris in Several Southeast Alaska Streams, Final Report. USDA Forest Service, Grant PNW-48. Juneau, Alaska.

118. **Tally, T.**, 1980. The Effects of Geology and Large Organic Debris on Stream Channel Morphology and Processes for Streams Flowing Through Old Growth Redwood Forests in Northwestern California. Ph.D. Thesis. University of California, Santa Barbara, California. 273p.

Large organic debris and the distribution of rock types along streams flowing through old growth redwood forests significantly influence channel form and fluvial processes in small to intermediate size streams. Both rock type and large organic debris are important in the development of the long profile, while large organic debris is especially significant in producing a diversity of channel morphology and sediment storage sites.

Specific climatic conditions of northwestern California help to support the unique and complex redwood forest ecosystem, dominated by the coast redwood tree (Sequoia sempervirens). As some of the earth's most heavily timbered hectares, the coastal redwood forest produces some of the tallest, largest and oldest trees on earth. The large size and longevity of the redwood trees has a profound effect on the quality and quantity of large organic debris accumulations found in stream channels draining redwood forests. The size of individual large organic debris ranges from 10 cm to 5.0 meters in diameter, and may exist in the stream channels for over two centuries.

Debris loading and distribution depend upon a variety of interrelated variables and processes, including: rock type, channel slope, hillslope angle, tree density, landsliding, floodplain formation, and hydraulic variables. Debris loading is generally inversely proportional to upstream drainage basin area and directly proportional to the tree density of redwoods proximal to the channel. Debris loading in the studied streams varies from 12 - 268 kilograms of large organic debris per square meter of active stream channel. Distribution of debris along the channel is more important than debris loading in determining the magnitude of debris contribution to the control of channel morphology.

Debris accumulations range from small and simple, single piece accumulations to large and complex accumulations up to 100 m long and containing several dozen large trunks. Debris accumulations are classified according to how they affect channel morphology. Process and morphologic effects of debris accumulations include: pool formation; control of sediment storage and distribution; influence on stream bank stability; size, shape, width and complexity of channel pattern; distribution of stream power along the channel; and the character of the longitudinal profile. Sixty percent of the length of the stream channel of Little Lost Man Creek is directly influenced by organic debris.

The distribution of resistant rock types along the channel of Little Lost Man Creek produces a convex profile. The slope of the profile at various scales is adjusted to rock type and large organic debris spacing, loading and accumulation type. For Little Lost Man Creek, organic debris controls 42 percent of the drop in elevation along the channel, and in combination with boulder debris, 58 percent of the drop. Seventy-eight percent of all the pools along the profile are related to accumulation of large organic debris. Pool depths are a function of rock type, as well as local channel slope, with pool depths being directly proportional to channel slope and to the percentage of massive sandstone underlying the channel.

Debris-related sediment storage sites cover 40 percent of the active stream channel along Little Lost Man Creek and help to buffer the movement of sediment along the channel. It is estimated that these sediment storage sites along Little Lost Man Creek contain 200 years of mean annual bedload discharge and that available storage space could hold another 100 years of bedload discharge.

It is concluded that large organic debris is an important part of the natural fluvial system in redwood forests and that proper management of hillslope and riparian, as well as stream, environments is necessary for the adequate protection of both the biological and physical characteristics of the stream environment.

119. **Toews, D.A., and M.K. Moore.** 1982a. The Effects of Streamside Logging on Large Organic Debris in Carnation Creek. Land Man. Rep. 11. Ministry of Forests, Province of British Columbia, Victoria, British Columbia. 29p.

The stability and volume characteristics of large organic debris in undisturbed and logged reaches of Carnation Creek were studied by comparing large scale maps prepared annually for four years before logging and two years following logging. Three reaches that were logged were compared to two that remained unlogged throughout the study. The results showed that the debris is less stable, the debris volumes are similar or lower, the number of pieces is greater, and the average piece size is smaller following logging. These changes are the result of the removal and breaking up of stable instream debris and the additional unstable debris during logging. The report presents preliminary data which indicates that coho fry populations initially increase as a result of the fine debris added immediately following logging but decrease with time as a consequence of channel alternations that resulted from the removal of stable debris. Streamside logging recommendations are presented that are directed towards maintaining the prelogging distribution and stability of organic debris.

120. ________________________ 1982b. The Effects of Three Streamside Logging Treatments on Organic Debris and Channel Morphology of Carnation Creek. p. 129-153. In G.F. Hartman (ed.): Proceedings: Carnation Creek Workshop, Malaspina College, 1982. Nanaimo, British Columbia.

In this paper, the impacts of three (rather than one) streamside logging treatments are evaluated. In addition to evaluating changes in large organic debris, changes in volume of small organic debris, in stream bed topography, and in rates of streambank erosion are evaluated.

Recommendations stress the importance of maintaining the stability and distribution of large debris that exists in the prelogging condition.

1. Trees should not be felled into or yarded across the stream channel.
2. Large stable pieces of debris should not be disturbed or removed during yarding.
3. Alder should not be felled into the stream.
4. Careful streamside logging should include removal of small pieces of debris such as limbs, branches, and small broken chunks from stream margins and streamside areas subject to flooding.
5. Leave strips can be an effective method of maintaining the prelogging conditions in the stream and do provide a source of large organic debris for the stream in the future.
6. Movement of debris introduced by logging continues for at least four years after logging.
7. Bridges and culverts should be designed to allow the passage of large organic debris.

121. **Tripp, D.B.** 1986. Using Large Organic Debris to Restore Fish Habitat in Debris-torrented Streams. Land Man. Rep. 47. Ministry of Forests, Province of British Columbia, Victoria, British Columbia. 26p.

Large organic debris (LOD) was introduced into a small debris-torrented stream in 1982 in an attempt to increase the amount of pool habitat available for overwintering coho. After one winter, the number of pools present in an experimental section of the stream increased from four to fourteen, the number pool types increased from three to six, pool area increased from 2.5 to 18.4%, and LOD cover increased from 2.2% of the wetted stream area to 11.2%. After a torrent-like summer flood and a second winter, the number of pools present had increased again to 21, while the amount of LOD cover and pool area was 17.7 and 15.4% of the total stream area available, respectively. By comparison, pool number, pool diversity, pool area, and LOD cover all remained relatively constant in a control section over the same time period. The stream was torrented again in the spring 1985, at which time the only structures still in place and functioning, were those that had been cabled to trees and stumps along the stream.

Compared to a control section, coho overwinter survival in the experimental section increased from 13 to 52% in the 1st year, while smolt production increased from 290 fish per kilometre of stream to 1050 fish per kilometre. The second year, coho survival declined to 10% and smolt production to 140 fish per kilometre of stream, but both were still considerably higher than those in the nearby torrented streams without new LOD. Benefit/cost analysis based on the first year's results indicated that the benefits derived from increases in coho production could pay for the cost of new LOD emplacements after five or six years, as long as there is no more mass wasting. Because three LOD emplacements were still creating new rearing habitat after a debris torrent, restoring LOD in streams is considered ti be a realistic and feasible way of offsetting some of the impacts of mass wasting in productive fish habitats. Further studies are now needed to determine what LOD configurations can be used to manipulate stream flows more precisely and improve fish spawning and rearing habitats. Such structures must be able to accommodate recurrent large scale sediment movements without blocking the stream and without being destroyed.

122. **Tripp, D.B. and V.A. Poulin.** 1986. The Effects of Mass Wasting on Juvenile Fish Habitats in Streams on the Queen Charlotte Islands. Land Man. Rep. No. 45. Ministry of Forests, Province of British Columbia, Victoria, British Columbia. 48p.

The effects of mass wasting, primarily debris torrents, on salmonid juvenile rearing habitat in streams on the Queen Charlotte Islands were assessed in 1981-1982 with a synoptic survey of 44 streams, followed later by a more detailed survey of seven streams in 1983-1984. Streams in the synoptic survey included both logged and unlogged streams, whereas only logged streams were included in the detailed survey. While it was not the intent of the study to assess the effects of logging per se on stream habitats, changes attributed to logging alone are also described.

Substantial reductions in both the quality and quantity of fish rearing habitat were found in first and second order perennial streams affected by debris torrents. the greatest impacts occurred in streams below 7% gradient, the general upper limit of the habitat utilized by species such as coho salmon. In these zones, debris torrents reduced average net pool depth by an estimated 20-40%, pool area by 38-45%, and undercut bank cover by 76%. Large organic debris (LOD) cover was also reduced by 57%, primarily because of a reduction in the number of LOD pieces present, and shifts in the orientation and position of LOD relative to stream flows. Other major changes included a significant increase in rooted stream width due to excessive scouring in sediment transport zones, and infilling and lateral channel movements in deposition zones. Dewatering reduced wetted stream width.

A comparison of winter and summer cover characteristics of torrented and non-torrented streams revealed that while summer cover properties changed as a function of torrenting there was no difference in total summer cover area between streams types. This was attributed to a shift from the root wads, coarse woody debris, undercut bank sand deep-water cover types found in non torrented streams to rock and boulder cover associated with surface turbulence in torrented streams. Winter cover characteristics included pools with woody debris, undercut banks and deep water where fish could seek refuge from high velocity storm flows. These features were reduced in torrented streams by 79%, and by 50% in intermediate streams (flood damaged and partly rehabilitated streams). In the most severely affected stream studied the total amount of suitable overwinter habitat in the entire accessible portion of stream averaged 0.4% of the stream area, compared to 17.8% in non-torrented streams - a decline of 98%.

Torrented streams had not only less cover than non-torrented streams, they also exhibited a more restricted range of habitats. There were no undercut banks associated with pools controlled by woody debris in any of the torrented reaches examined, and only rarely were rootwads present. In addition, woody debris cover located in pools of non-torrented streams was almost always associated with abundant deep-water cover. In contrast, pools associated with woody debris in torrented streams were comparatively small and shallow in relation to the amount of debris present.

Seventy-three percent of pools in the non-torrented reaches were formed by scouring around LOD, compared to only 40% of pools in torrented reaches. Boulders, in contrast, accounted for 46% of the pools scoured out in torrented reaches, but only 13% on non-torrented reaches. Where non-torrented streams usually had a complex assemblage of LOD controlled lateral scour, plunge, backwater, and dammed pools, torrented streams typically had only simple lateral scour and cascading "pocket type" pools.

When they first occur, debris torrents affect, on average, the upper two-thirds of habitat available to anadromous fish in first- and second-order logged streams. Significantly less habitat is affected in unlogged streams. Downstream of directly affected stream reaches, there were no obvious changes to fish rearing habitat, apart from those caused by logging. From the synoptic survey data, effects attributed strictly to logging included a 27% reduction in woody debris cover or about half the amount removed by mass wasting, and a 74% reduction in undercut bank area about the same removed by mass wasting.

123. **Triska, F.J.** 1984. Role of Woody Debris in Modifying Channel Geomorphology and Riparian Areas of a Large Lowland River Under Pristine Conditions: A Historical Case Study. Verhandlungen-Internationale Vereinigung fuer Theorelifche und Angewandte Limnologie (International Association of Theoretical and Applied Limnology) 22: 1876-1892.

This report demonstrates the role of wood debris in: (1) modifying riparian areas by creation of lakes, (2) altering the function of tributary channels and (3) modifying the main channel of the Red River in Louisiana, U.S.A. The period of record is 1827 to 1920.

Historical records were reviewed to estimate the impact of wood debris on a 400-500 km reach of the Red River, Louisiana, U.S.A. In the primal condition the banks consisted of unstable alluvial deposits easily eroded during floods. Sediment and riparian trees from eroded banks formed organic debris jams which blocked the channel and promoted channel aggradation. Over a period >375 years wood debris dams formed in series. Debris dams remained in place 80-150 years.

Wood debris impacted adjacent riparian areas by flooding forests and forming a series of large lakes. Under natural conditions lakes could become nearly permanent features of the riparian landscape if tributary channels filled with alluvium and organic debris. After removal of organic debris the most recently formed lakes drained over a period of approximately 30 years. Impoundment of water in the main river channel reversed the direction of flow in many tributary streams, especially at high discharge. Flow reversal in tributaries resulted in channel enlargement and diversion of one-half to three-quarters of the rivers discharge adjacent to riparian lowlands. Wood debris reduced the river's width from approximately 185 m to approximately 40 m, and aggraded the river bed a maximum of 7 m. Tributary channels were dammed or filled with organic debris, and the river was permanently opened to navigation in 1873. Restoration of full channel flow exposed previously buried logs and eroded forested banks. By 1904, seventy years of debris dams and snag removal, levee projects, dredging and cutting bankside trees resulted in a cleared, wide, meandering channel, which might today be mistaken as typical of a pristine lowland river.

124. __________ **and K. Cromack.** 1980. The Role of Woody Debris in Forest and Streams. p. 171-190. In R.H. Waring (ed.): Forests: Fresh Perspectives From Ecosystem Analysis. Oregon State University, Corvallis, Oregon.

In the Pacific Northwest, old-growth forests and their associated streams contain large quantities of coarse woody debris. To date, such debris has been considered an impediment to reforestation and stream quality. Consequently it has been virtually ignored in ecological studies. In this paper, the authors attempt to correct that omission by exploring how wood debris is utilized in forest and stream ecosystems.

The authors begin with determining the amounts of wood debris in various forest and stream ecosystems and its rates of accumulation in each; how debris modifies existing habitats and creates new ones; how rapidly coarse woody debris breaks down into its component elements and how its carbon and other elements are recycled; and finally, a discussion of what implications these data have for managers of forested watersheds in the Pacific Northwest. The removal of natural, stable woody debris from streams can damage both the stream channel and the streamside riparian habitat. Consequently, such material should be left in place where when possible. In cases where massive accumulations occur, either as a result of logging or catastrophic events such as debris avalanches, significant wood removal may be necessary. In such cases, the advice of competent stream ecologists and geomorphologists should be sought before removal of massive debris jams are attempted. The general goal for wood management in streams should be to maintain well-established debris so that it can continue to function both as habitat and as a long term nutrient source to stream organisms.

125. **Vanderhayden, J.** 1984. In Stream Woody Debris Management: An Example From Western Oregon. USDA Forest Service Rpt. Willamette National Forest, Oak Ridge, Oregon.

126. **Ward, G.M. and N.G. Aumen.** 1986. Woody Debris as a Source of Fine Particulate Organic Matter in Coniferous Forest Stream Ecosystems. Can. J. Fish. Aquat. Sci. 43: 1635-1642.

The potential contribution of woody debris to fine particulate organic matter pools (0.45 m ≤FPOM <1 mm) was investigated in a coniferous forest stream ecosystem in western Oregon. The amount of wetted surface area of both large (>10 cm) and fine woody debris (1-10 cm) was 0.018 and

0.069 m^2 m^{-2} stream bed, respectively, during summer base flow. These values increase to 0.062 and 0.195 m^2 m^{-2} stream bed during winter flows. Studies of vertical distribution indicated that most fine wood is concentrated within 0.3 m of the stream bottom, while large wood is more evenly distributed up to 0.7 m. Lignin concentrations of large wood, soil, and FPOM were very similar. Examination of FOPM samples with scanning electron microscopy revealed an abundance of wood-derived particles. Erosion rates of wood surfaces ranged between 0,5 and 11 mm yr^{-1} depending on decay state of the log. Using conservative estimates of processing rates, woody debris could be a source for approximately 90 g m^{-2},31 yr^{-1} of FOPM, but with slightly a less conservative estimate, wood processing could easily generate several times the FPOM that is contributed by leaf and needle litter.

127. **Wilford, D.J.** 1984. The Sediment-Storage Function of Large Organic Debris at the Base of Unstable Slopes. p. 115-119. In W.R. Meehan, et al. (eds.): Proceedings: Symposium on Fish and Wildlife Relationships in Old Growth Forests. Am. Inst. of Fish. Biol.

Large organic debris in old-growth forests provides important sediment-storage elements on hillslopes. As the old-growth trees fall or blow down across the slope, they form a series of cross slope obstructions. Sediments and small organic debris from upslope mass movements are deposited behind these obstructions, forming a series of terraces which temporarily delay the delivery of sediments to stream channels. Documentation of this storage role of large organic debris is provided from an old-growth Sitka spruce-western hemlock forest site in the Queen Charlotte Islands of British Columbia.

128. **Wilson, K.V.** 1973. Changes in Flood Flow Characteristics of a Rectified Channel Caused by Vegetation, Jackson, Mississippi. USGS. J. Res., 1(5): 621-625.

Extreme changes in velocity, stage, and Manning's roughness coefficient, n, were observed during the first year after canalization of Hanging Moss Creek at Jackson, Miss. Additional changes were observed during the following 8 years. The channel, constructed during the summer of 1963, had a 50-foot-wide bottom, 2:1 side slopes, and 12-foot depth. In March 1964, average velocities of 7.8 feet per second were measured at a 5 1/2-foot depth of the clean channel and Manning's n, was computed to be 0.022. In October 1964 the average velocity was 3.2 fps at a 5 1/2-foot depth and Manning's n was 0.045. The channel was then lined with fairly thick vegetation consisting of small willows, weeds, and grass. In October 1970 (summer foliage existing) the average velocity was 2.0 fps at a 5 1/2-foot depth and Manning's n was 0.07. Willow trees, 8 to 10 feet high, then lined the channel. In March 1971 (barren foliage), Manning's n was 0.05. In March 1972 (barren foliage), Manning's n was increased to 0.07.

These observations indicate that the commonly used values of Manning's n for channel rectification (0.02-0.03) are low and that the carrying capacity of earthen channels may be reduced 50 percent as a result of only 1 year's growth of vegetation and 70 percent as a result of 8 year's growth. The carrying capacity during summer foliage is approximately two-thirds the carrying capacity during barren winter foliage.

129. **Zimmerman, R.C., J.C. Goodlett, and G.H. Comer.**, 1967. The Influence of Vegetation on Channel Form of Small Streams. Internat. Assoc. of Sci. Hydrol. 75: 255-275.

Data on channel width of several small streams in the Sleepers River basin of northern Vermont have provided some measure of the influence of vegetation on channel form. Along 5 streams, for which there are complete records of variation in channel width, width does not increase in a downstream direction as far as points with drainage areas of 0.2 to 0.8 square mile, presumably as a result of disturbance and encroachment by vegetation. In one basin with an area of 0.8 square mile, channel width is clearly related to type of vegetation, as the channel is alternately wide under forest, and narrow in sod. Along one stream, width increases in response to increases in discharge where the drainage area exceeds 0.3 square mile, but the variability in width (expressed as the standard deviation from mean and as a coefficient of relative variability) also increases, reaching a maximum where the drainage area is about 2 square miles. Relatively uniform channel widths occur, on the other hand, where the drainage area is about 6 square miles. Similar relationships were found in other streams sampled. In one stream, however, the mean channel width under forest where the drainage area is about 1.3 square mile exceeds by more than 5 feet the mean width of the same stream where the drainage area is 2.8 square miles and the vegetation along the stream is predominately sod.

In the Sleepers River basin there are apparently two thresholds along streams. In a downstream direction, the first threshold occurs at points with drainage areas of 0.2 to 0.8 square mile. Upstream from these points, width does not increase in a downstream direction, living tree roots cross the channel, and dams of organic debris are common. The flow is commonly underground. Points with drainage areas of about 0.2-0.8 square mile have annual high flows of 10 to 20 cfs. With drainage areas exceeding 0.2-0.8 square mile widths increase, but channel form is highly variable, and mean widths may vary by as much as 5 feet depending upon the type of vegetation. Relatively uniform widths occur, regardless of vegetation, where the drainage area exceeds 4 to 6 square miles. Points with drainage areas of about 5 square miles are apparently the second threshold. These points have annual high flows in the range of 100 to 150 cfs. Beyond these points, the influence of vegetation on channel form is marginal compared with that of geologic differences and the sinuosity of the flow itself.

Vegetation influences channel form by altering the roughness and shear strength of bed and banks. In addition, non-fluvial processes such as the windthrow or frost-heaving of streambank trees may locally double or triple the channel dimensions that would occur with the same discharge regimen in the same geologic setting.

SUMMARY

Large organic debris plays a major role by influencing both the physical and biological characteristics of small and intermediate sized streams and to a lesser extent those of larger sized streams. Organic debris in streams increase the aquatic habitat diversity by locally influencing channel morphology and the creation of protected backwater areas, energy dissipation of flowing water, acting as sediment traps, and providing nutrients and substrate for biological activity. A diverse physical habitat is maintained by anchoring the position of pools along the direction of the stream, creating backwaters along the stream margin, causing lateral migration of the channel and forming secondary channel systems, and increasing the depth variability.

The forest adjacent to a stream (or associated lake - lake shores are a primary sources of LOD in lake headed stream systems) supplies large organic debris to channels in the form of root wads, trunks, and limbs of trees. The debris enters stream channels by a variety of mechanisms such as tree blowdown, bank undercutting and collapse, mass movement processes on adjacent hillslopes or by flotation from source lakes. Within a drainage basin resource use activities by man can also be responsible for direct and/or indirect introduction of organic debris into the stream channel. The debris moves through the stream channel by flotation at high water, in torrents and as dissolved and fine particulate matter following breakdown by wood processing organisms.

Stable debris is important in the maintenance of fish habitat. Pool formation as a result of large, stable, organic debris is significant summer and winter habitat for several species of salmonids. Most species prefer pools during base streamflows in winter, the level of preference being largely determined by pool quality and abundance of woody debris. Large, stable debris also attracts fish to pools along the stream edge as opposed to those in mid channel. Slack water refuges during periods of high stream flow are associated with large debris. The debris is also utilized as protective cover by young salmonids.

Major contributing factors to debris stability are, size, including length and diameter and the presence of rootwads or branches. Branches and rootwads increase the mass and surface area available for snagging or instream obstruction, thus whole trees are potentially more stable than tree fragments. Relatively short pieces of debris can be stable in narrow channels, but longer pieces are necessary for stability in wider channels. Other factors that influence debris stability are orientation to axis of flow, proportion of debris that lies in water, and degree of burial (partial burial or anchoring of one end is less effective than complete burial or anchoring of both ends in or on the streambed or bank in preventing down stream transport of organic debris during high flows).

Large organic debris increases the complexity of stream habitats by physically obstructing waterflow. Debris extending partially across the channel deflect the current laterally which may result in channel widening. Debris also creates variation in channel depth by producing scour pools downstream from obstructions. Hydraulic complexity is increased by sediment storage especially in low gradient streams with wide, shallow channels possessing a high diversity of riffles and pools. In large streams where large organic debris cannot span the main channel, debris accumulations along the banks can create secondary channel systems that can become important rearing and spawning habitat.

Removal of large, stable organic debris reduces channel stability and the quality of pools and cover. Downstream spawning and rearing habitats may be damaged by large increases in sediment released from storage when stable debris is removed. With the removal of stable debris in smaller and mid sized streams the proportion of riffles tends to increase and pools decrease. Young salmonid species which prefer riffle habitats may increase in abundance whereas those salmonid species which prefer pool habitat are correspondingly reduced.

Instream management and adjacent forest management practices (e.g. forest harvesting) should include sound planning for the maintenance of the natural distribution and stability of large organic debris and the use of natural stream processes to regulate channel conditions. Integrated watershed management should be applied; the leaving of a wide buffer strip to ensure the production of a continuous long term supply of large organic debris and to help minimize alteration of stream area, minimizing of the debris avalanche potential and hence the debris torrent potential, the minimizing of the addition of fresh material to the channel, and the leaving of large, stable organic debris within the channel should be considered in any decision process.

LOD creation in stream channels as a stream enhancement, restoration and mitigation technique has not moved beyond the research and development phase. The largest scale effort to date in British Columbia is at the Nechako River in the central interior of British Columbia, where 38 LOD mitigation structures have been installed with a goal of about 200.

It is only recently that large organic debris has been recognized by those involved with aquatic ecology, hydrology, and geomorphology as being an important and integral part of forested stream systems. Understanding the behaviour and functional importance of LOD is still rudimentary given the incredible diversity of processes and relationships associated with it. A lack of baseline data reduces the information value if studies are of a short term duration and not approached from a watershed basis. A much needed team approach with increased integration of expertise between the disciplines of earth science and biological science with regards to large organic debris and its relation to stream channels and aquatic habitat should be actively pursued.

APPENDIX I

Subject Index:

The index lists references under a general subject title. Subject titles are listed alphabetically and are followed by the reference number of the article.

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Woody Debris Removal (See Debris Removal).

APPENDIX II

Author Index:

The authors of the references are listed alphabetically. The index listing also includes the reference publication date and the reference number of the article. References that were not available to the present author for annotation at the time of writing are indicated by an asterisk (*) placed in front of the referenced authors name. References where the authors summary or conclusions have been used for the annotation are indicated by a plus symbol (+) placed in front of the referenced authors name.

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Andrus, C.W., B.A. Long, and H.A. Froehlich	88	(2.)
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*Berry, J.D.	75	(6.)
Beschta, R.L.	79	(7.)
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*Bilby, R.E.	77	(11.)
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APPENDIX III

Chronological Index:

The references are listed chronologically by year of publication. The index listing also includes the authors name and the reference number of the article.

YEAR	AUTHOR	REF. NUMBER
1966	Helmers, A.E.	(54.)
1967	Zimmerman, R.C., J.C. Goodlett, and G.H. Comer	(129.)
1969	Meehan, W.R. et al.	(87.)
	Sheridan, W.L.	(102.)
1972	Heede, B.H. (a)	(50.)
	Heede, B.H. (b)	(51.)
	Lammel, R.F.	(71.)
1973	Gibbons, D.R. and E.O. Salo	(38.)
	Wilson, K.V.	(128.)
1975	Berry, J.D.	(6.)
	Bustard, D.R. and D.W. Narver	(28.)
	Froehlich, H.A.	(36.)
	Russell, L.R.	(96.)
	Swanson, F.J. and G.W. Lienkaemper	(113.)
1976	Keller, E.A., W.N. Melhorn, and M.C. Gardner	(64.)
	Megahan, W.F. and R.A. Nowlin	(89.)
	Smith, D.G.	(106.)
	Swanson, F.J., G.W. Lienkaemper, and J.B. Sedell	(116.)
1977	Bennett, J.R. and M.J. Selby	(5.)
	Bilby, R.E.	(11.)
	Hall, J.D. and C.D. Baker	(48.)
	Sedell, J.B. and F.J. Triska	(101.)
	Swanson, F.J., J.B. Sedell, and G.W. Lienkaemper	(117.)
1978	Swanson, F.J. and G.W. Lienkaemper	(114.)
	Lestelle, L.C.	(72.)
	Marston, R.A.	(84.)

1979	Baker, C.O.	(4.)
	Beschta, R.L.	(7.)
	Bilby, R.E.	(12.)
	Keller, E.A. and F.J. Swanson	(65.)
	Keller, E.A. and T. Tally	(66.)
1980	Bilby, R.E. and G.E. Likens	(16.)
	Bryant, M.D.	(23.)
	Canada Department Fisheries and Oceans and British Columbia Ministry of Environment.	(29.)
	Kelsey, H.M.	(67.)
	Marston, R.A.	(85.)
	Stern, D.H. and M.S. Stern (a)	(109.)
	Stern, D.H. and M.S. Stern (b)	(110.)
	Tally, T.	(118.)
	Triska, F.J. and K. Cromack	(124.)
1981	Bilby, R.E.	(13.)
	Everest, F.H. and W.R. Meehan	(34.)
	Keller, E.A., A. MacDonald, and T. Tally	(63.)
	Mosely, M.P.	(90.)
1982	Andrews, E.D.	(1.)
	Bisson, P.A. et al.	(19.)
	Bryant, M.D.	(24.)
	Duff, D.A. and R.S. Wydoski	(32.)
	Frear, S.T.	(35.)
	Likens, G.E. and R.E. Bilby	(75.)
	Lisle, T.E.	(76.)
	MacDonald, A., E.A. Keller and T. Tally	(82.)
	Marston, R.A.	(86.)
	Megahan, W.F.	(88.)
	Sedell, J. R. and K.J. Luchessa	(99.)
	Swanson, F.J. and G.W. Lienkaemper	(115.)
	Toews, D.A. and M.K. Moore (a)	(119.)
	Toews, D.A. and M.K. Moore (b)	(120.)
1983	Beschta, R.L. (a)	(8.)
	Beschta, R.L. (b)	(9.)
	Bryant, M.D.	(25.)
	Lyons, J.K. and R.L. Beschta	(80.)
	Sheilds, F.D.	(103.)

1984	Angermeier, P.L. and J.R. Karr	(3.)
	Bilby, R.E.	(14.)
	Bisson, P.A. and J.R. Sedell	(20.)
	Bustard, D.A.	(27.)
	Grant, G.E., M.J. Crosier and F.J. Swanson	(42.)
	Gurnell, A.M. and K.J. Gregory	(47.)
	Hickin, E.J.	(55.)
	Lestelle, L.C. and C.J. Cederholm	(73.)
	Sedell, J.R. and J.L. Froggatt	(98.)
	Sedell, J.R., F.J. Swanson, and S.V. Gregory	(100.)
	Shields, D.F. and N.R. Nunnally	(104.)
	Speaker, R., K. Moore, and S. Gregory	(107.)
	Swanson, F.J. et al.	(112.)
	Triska, F.J.	(123.)
	Vanderhayden, J.	(125.)
	Wilford, D.J.	(127.)
1985	Bilby, R.E.	(15.)
	Bryant, M.D.	(26.)
	Gregory, K.J., A.M. Gurnell, and C.T. Hill	(45.)
	Grette, G.B.	(46.)
	Hogan, D.L.	(58.)
	Murphy, M.L. et al.	(91.)
1986	Beschta, R.L. and W.S. Platts	(10.)
	Boehne, P.L. and J.R. Wolfe	(22.)
	Dolloff, A.C.	(31.)
	Elliot, S.T.	(33.)
	Grant, G.E.	(39.)
	Harmon, M.E. et al.	(49.)
	Hogan, D.L.	(57.)
	House, R.A. and P.L. Boehne	(60.)
	Lisle, T.E. (a)	(77.)
	Lisle, T.E. (b)	(78.)
	Murphy, M.L. et al.	(92.)
	Tripp, D.B.	(121.)
	Tripp, D.B. and V.A. Poulin	(122.)
	Ward, G.M. and N.G. Aumen	(126.)

1987	Bisson, P.A. et al.	(18.)
	Grant, G.E.	(40.)
	Hogan, D.L.	(58.)
	Klein, R., D. Sonnevil, and D. Short	(68.)
	Kochel, R.C.	(69.)
	Kochel, R.C., D.F. Ritter, and J. Miller	(60.)
	Lienkaemper, G.W. and F.J. Swanson	(74.)
	Long, B.A.	(79.)
	MacDonald, A. and E.A. Keller	(81.)
	Sullivan, K. et al.	(111.)
1988	Andrus, C.W., B.A. Long, and H.A. Froehlich	(2.)
	Bisson, P.A., K. Sullivan, and J.L. Nielsen	(21.)
	Grant, G.E.	(41.)
	Gregory, K.J. and A.M. Gurnell	(44.)
	Kaufmann, P.R.	(62.)
	MacDonald, J.S., G. Miller, and R.A. Stewart	(83.)
	Robison, E.G.	(94.)
	Sedell, J.B. et al.	(97.)
1989	Bilby, R.E. and J.W. Ward	(17.)
	Heimann, D.C.	(53.)
	Hogan, D.L. and M. Church	(59.)
	Stack, W.R.	(108.)
1990	Carlson, J.Y., C.W. Andrus, and H.A. Froehlich	(30.)
	Gibbons, D.R. et al.	(37.)
	Grant, G.E., F.J. Swanson, and M.G. Wolman	(43.)
	Heede, B.H. and J.N. Rinne	(52.)
	House, R.A. and V. Crispin	(61.)
	Nechako Fisheries Conservation Program Steering Committee.	(93.)
	Robison, E.G. and R.L. Beschta	(95.)
	Shirvell, C.S.	(105.)

APPENDIX IV

References by Geographic Area:

The index lists references by geographic area in which the study was conducted or applies to. The geographic areas are listed alphabetically with references listed alphabetically by authors name. The index also includes the publication date and the reference number of the article.

AUTHOR	YEAR OF PUB.	REF. NUMBER
ALASKA		
Bryant, M.D.	80	(23.)
Bryant, M.D.	82	(24.)
Bryant, M.D.	85	(26.)
Dolloff, A.C.	86	(31.)
Elliot, S.T.	86	(33.)
Gibbons, D.R. et al.	90	(37.)
Helmers, A.E.	66	(54.)
Lisle, T.E.	86b	(78.)
Meehan, W.R. et al.	69	(87.)
Murphy, M.L. et al.	85	(91.)
Murphy, M.L. et al.	86	(92.)
Robison, E.G.	88	(94.)
Robison, E.G. and R.L. Beschta	90	(95.)
Sheridan, W.L.	69	(102.)
Swanson, F.J. et al.	84	(112.)
Swanson, F.J., J.B. Sedell, and G.W. Lienkaemper	77	(117.)
ALBERTA		
Smith, G.G.	76	(106.)

BRITISH COLUMBIA

Bustard, D.R	84	(27.)
Bustard, D.R. and D.W. Narver	75	(28.)
Canada Department of Fisheries and Oceans and British Columbia Ministry of Environment.	80	(29.)
Hickin, E.J.	84	(55.)
Hogan, D.L.	85	(56.)
Hogan, D.L.	86	(57.)
Hogan, D.L.	87	(58.)
Hogan, D.L. and M. Church	89	(59.)
Nechako Fisheries Conservation Program Steering Committee.	90	(93.)
Shirvell, C.S.	90	(105.)
Toews, D.A.A. and M.K. Moore	82a	(119.)
Toews, D.A.A. and M.K. Moore	82b	(120.)
Tripp, D.B.	86	(121.)
Tripp, D.B. and V.A. Poulin	86	(122.)
Wilford, D.J.	84	(127.)

CALIFORNIA - NORTHWEST

Keller, E.A., A. MacDonald and T. Tally	81	(63.)
Keller, E.A. and T. Tally	79	(66.)
Kelsey, H.M.	80	(67.)
Klein, R., R. Sonnevil, and D. Short	87	(68.)
Lisle, T.E.	82	(76.)
Lisle, T.E.	86a	(77.)
MacDonald, A. and E.A. Keller	87	(81.)
MacDonald, A., E.A. Keller, and T. Tally	82	(82.)
Tally, T.	80	(118.)

COLORADO

Heede, B.H.	72a	(50.)
Heede, B.H.	72b	(51.)

ENGLAND

Gregory, K.J. and A.M. Gurnell	88	(44.)
Gregory, K.J., Gurnell A.M. and Hill C.T.	85	(45.)
Gurnell, A.M. and K.J. Gregory	84	(47.)

IDAHO

Megahan, W.F.	82	(88.)
Megahan, W.F. and R.A. Nowlin	76	(89.)

ILLINOIS

Angermeier, P.L. and J.R. Karr	84	(3.)

LOUISIANA

Triska, F.J.	84	(123.)

MISSISSIPPI

Wilson, K.V.	73	(128.)

NEW ENGLAND

Likens, G.E. and R.E. Bilby	82	(75.)

NEW HAMPSHIRE

Bilby, R.E.	81	(13.)
Bilby, R.E. and G.L. Likens	80	(16.)

NEW ZEALAND

Bennett, J.R. and M.J. Selby	77	(5.)
Mosely, P.M.	81	(90.)

NORTH CAROLINA

Keller, E.A. and F.J. Swanson	79	(65.)

OREGON

Andrus, C.W., B.A. Long, and H.A. Froehlich	88	(2.)
Baker, C.O.	79	(4.)
Beschta, R.L.	79	(7.)
Beschta, R.L. and W.S. Platts	86	(10.)
Boehne, P.L. and J.R. Wolfe	86	(22.)
Carlson, J.Y., C.W. Andrus, and H.A. Froehlich	90	(30.)
Grant, G.E.	86	(39.)
Grant, G.E.	87	(40.)
Grant, G.E.	88	(41.)

Grant, G.E., M.J. Crosier and F.J. Swanson	84	(42.)
Grant, G.E., F.J. Swanson, and M.G. Wolman	88	(43.)
Heimann, D.C.	89	(53.)
House, R.A. and P.L. Boehne	86	(60.)
House, R.A. and V. Crispin	90	(61.)
Kaufmann, P.R.	88	(62.)
Keller, E.A. and F.J. Swanson	79	(65.)
Lammel, R.F.	72	(71.)
Lienkemper, G.W. and F.J. Swanson	87	(74.)
Long, B.A.	87	(79.)
Lyons, J.K. and R.L. Beschta	83	(80.)
Marston, R.A.	78	(84.)
Marston, R.A.	80	(85.)
Marston, R.A.	82	(86.)
Sedell, J.R. et al.	88	(97.)
Sedell, J.R. and J.L. Froggatt	84	(98.)
Speaker, R., K. Moore, and S. Gregory	84	(107.)
Stack, W.R.	89	(108.)
Swanson, F.J. and G.W. Lienkaemper	75	(113.)
Swanson, F.J. and G.W. Lienkaemper	78	(114.)
Swanson, F.J., G.W. Lienkaemper, and J.R. Sedell	76	(116.)
Vanderhayden, J.	84	(125.)
Ward, G.M. and N.G. Aumen	86	(126.)

PACIFIC NORTHWEST - GENERAL AREA

Beschta, R.L.	83b	(9.)
Bisson, P.A. et al.	87	(18.)
Bryant, M.D.	83	(25.)
Everest, F.H. and W.R. Meehan	81	(34.)
Fear, S.T.	82	(35.)
Froehlich, H.A.	75	(36.)
Grant, G.E.	88	(41.)
Hall, J.D. and C.D. Baker	77	(48.)
Keller, E.A. and F.J. Swanson	79	(65.)
Sedell, J.R. et al.	88	(97.)
Sedell, J.R. and K.J. Luchessa	82	(99.)
Sedell, J.R., F.J. Swanson, and S.V. Gregory	84	(100.)
Sedell, J.R. and F.J. Triska	77	(101.)
Sullivan, K. et al.	87	(111.)
Triska, F.J. and K. Cromack	80	(124.)

U.S.A. - MIDWEST AND SOUTHEAST

Keller, E.A., W.N. Melhorn, and M.C. Gardiner	76	(64.)

VERMONT

Zimmerman, R.C., J.C. Goodlett, and G.H. Comer	67	(129.)

VIRGINIA

Kochel, R.C., D.F. Ritter and J. Miller	87	(70.)

WASHINGTON

Bilby, R.E.	84	(14.)
Bilby, R.E.	85	(15.)
Bilby, R.E. and J.W. Ward	89	(17.)
Bisson, P.A. et al.	87	(18.)
Bisson, P.A. et al.	82	(19.)
Bisson, P.A. and J.R. Sedell	84	(20.)
Bisson, P.A., K. Sullivan, and J.L. Nielsen	88	(21.)
Grette, G.B.	85	(46.)
Lestelle, L.C.	78	(72.)
Lestelle, L.C. and C.J. Cederholm C.J.	84	(73.)
Swanson, F.J. and G.W. Lienkaemper	82	(115.)

WYOMING

Andrews, E.D.	82	(1.)

NON SPECIFIC AREA - OR AREA NOT INDICATED IN REFERENCE

Berry, J.D.	75	(6.)
Beschta, R.L.	83a	(8.)
Bilby, R.E.	77	(11.)
Bilby, R.E.	79	(12.)
Duff, D.A. and R.S. Wydoski	82	(32.)
Gibbons, D.R. et al.	90	(37.)
Gibbons, D.R. and E.A. Salo	73	(38.)
Heede, B.H. and J.N. Rinne	90	(52.)
Harmon, M.E. et al.	86	(49.)
Kochel, R.C.	87	(69.)
MacDonald, J.S., G. Miller, and R.A. Stewart	88	(83.)
Russell, L.R.	75	(96.)
Shields, D.F.	83	(103.)
Shields, D.F. and N.R. Nunnally	84	(104.)
Stern, D.H. and M.S. Stern	80a	(109.)
Stern, D.H. and M.S. Stern	80b	(110.)

APPENDIX V

List of References Not Annotated:

The following is a list of those references that were not available for annotation at the time of writing. The references are listed alphabetically by authors name. The listing also includes the reference publication date and the reference number of the article.

AUTHOR	YEAR OF PUB.	REF. NUMBER
Berry, J.D.	75	(6.)
Beschta, R.L.	83a	(8.)
Beschta, R.L.	83b	(9.)
Bilby, R.E.	77	(11.)
Bilby, R.E.	79	(12.)
Bisson, P.A. and J.R. Sedell	84	(20.)
Everest, F.H. and W.R. Meehan	81	(34.)
Grant, G.E.	86	(39.)
Gurnell, A.M. and K.J. Gregory	84	(47.)
Hall, J.D. and C.D. Baker	77	(48.)
Hogan, D.L.	85	(56.)
House, R.A. and V. Crispin	90	(61.)
Kochel, R.C.	87	(69.)
Lestelle, L.C.	78	(72.)
Long, B.A.	87	(79.)
MacDonald, A., E.A. Keller, and T. Tally	82	(82.)
Marston, R.A.	78	(84.)
Marston, R.A.	80	(85.)
Robison, E.G.	88	(94.)
Swanson, F.J. and G.W. Lienkaemper	82	(115.)
Swanson, F.J., J.B. Sedell, and G.W. Lienkaemper	77	(117.)
Vanderhayden, J.	84	(125.)